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1927-1928

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# Foreword

IN INTRODUCING to researchers in engineering the present volume of the TRANSACTIONS of The American Society of Mechanical Engineers, an explanation of the changes which have taken place in its physical appearance and its contents is due.

## CHANGE IN PUBLICATION POLICY

A revision of the publication policy of the A.S.M.E. consummated in 1928 resulted in important changes in the TRANSACTIONS. Physically, the page size was increased to conform to that of the Society's journal *Mechanical Engineering*. In order to bring the published papers of the Society more quickly to its members, and to bring to each member only the papers in which he had an interest, the old plan of publishing once a year a single volume, expensively bound and sent without charge to every member of the Society, was abandoned in favor of a radically different scheme.

The new plan provides for the issuing in pamphlet form of groups of selected papers presented at meetings and other miscellaneous contributions. These pamphlets, forming sections of the TRANSACTIONS, are issued periodically at the rate of about three a month, and each section is sponsored by one of the Society's professional divisions.

The new plan has made possible a change in the principles underlying the selection of papers for inclusion in the TRANSACTIONS. Under the old plan, publication was delayed by the custom of printing but once a year, and this delay, combined with the expense, limited the choice of papers to a relatively few which were considered to be of permanent reference value. Much valuable material which could not be presented in the Society's journal, *Mechanical Engineering*, was therefore excluded from publication.

Under the new plan a member of the Society may register in any three professional divisions and may receive, without cost, the sections of the TRANSACTIONS which are sponsored by these divisions. The periodical publication of these sections in magazine form has a feature of timeliness which justifies the inclusion of papers of possible temporary interest. It also offers a medium for the printing of papers of specific interest to a single group of members without the cost of distribution to all.

The new policy, combined with increased activity on the part of the professional divisions, has made available a much greater number of engineering papers, as may be judged by comparing volume 48 (1926) with its 38 papers and the present volume with its 257 papers.

## COMPLETE TRANSACTIONS FOR DEPOSITORIES AND LIBRARIES

For permanent record and for reference use in libraries, and in the Society's depositories all over the world, a number of sets comprising all of the sections of TRANSACTIONS have been provided. When each section of the TRANSACTIONS was printed, extra impressions were laid aside, and these have been bound in the two books which form parts I and II of volume 49–50.

## Volumes 49 and 50 Published Together as Volume 49-50

The valuable feature of a shorter time interval between the presentation of a paper and its publication under the new plan made it possible to publish the papers which would have comprised volumes 49 (1927) and 50 (1928) under the old plan simultaneously during 1928 without delaying the appearance of the 1927 papers. (Under the old plan volume 49 would have appeared in book form in the summer of 1928.)

The division of the complete Transactions into two books known as parts I and II is for convenience in binding and does not differentiate volumes 49 and 50. No differentiation exists. The combined volume is known as volume 49-50 (1927-1928). In numbering the papers in accordance with the scheme outlined below, all papers are referred to as of volume 50.

## Numbering of Papers and Arrangement in Complete Transactions

The definite sponsorship of every paper by one of the professional divisions has led to the abandonment of the former system of numbering papers serially. The new system designates each paper by a symbol composed of key letters and significant numbers. The letters refer to the section of Transactions to which the paper is assigned. Thus AER refers to the Aeronautic section, IS to the Iron and Steel section, etc. The first number which follows the letters is the volume number, as volume 50, and the second is the serial number within the section of the paper in question. Thus FSP-50-3 indicates that the paper so numbered is a part of the Fuels and Steam Power section of volume 50 of Transactions, and is the third paper of that series. The arrangement of papers in the bound Transactions is alphabetical by sections, and numerical within the section. All papers of the Management section, for instance, will be found together in numerical order under the symbol MAN.

## How to Use the Index

In each of the two books forming parts I and II of volume 49-50 will be found a complete index to both parts of the volume so that either may be consulted. Reference to the individual items comprising the index is by paper number, explained above, the page number being included in parentheses. Thus MH-50-8 (15) means that the reference is to be found in the Materials-Handling section, vol. 50, paper no. 8, page 15. In part I of the bound volume are all papers belonging to sections whose key letters are between AER and FSP, and in part II all those whose key letters are between HYD and WDI.

## Concerning Blank Pages

In order to make the papers comprising the Transactions available as reprints, it is necessary to print them so that the number of pages they contain is a multiple of four. This accounts for the blank pages which will be found scattered throughout the volume.

The Publications Committee.

# Progress in Hydraulics

## Contributed by the Hydraulic Division

Executive Committee: Ely C. Hutchinson, *Chairman*, H. L. Doolittle, *Secretary*, H. Birchard Taylor, R. L. Thomas, and W. M. White

THE YEAR 1927 has seen marked progress in practically all branches of industry related and of interest to the Hydraulic Division. The country as a whole has enjoyed an increased growth somewhat better than normal. While there has been no one thing outstanding, a review of what has happened during the year indicates a distinct trend.

The light and power industry in which the membership of the Hydraulic Division centers the greater part of its activity, is serving close to a million and a half new customers since the date of our last progress report. The greatest increase has been in the number of domestic-lighting customers. The increase in the use of industrial power and commercial-lighting power has nevertheless been well maintained and shows a healthy increase. In particular, the growth in the use of electricity in the rural districts is worthy of special mention.

### Economic and Political Aspects

The economics of electric-utility operation is receiving increased attention, and one of the results of this is an increase in the interconnection of electric systems. There are now in fact eighteen electric systems in the United States each having an annual output of one billion kilowatt-hours or more.

Increased efficiency in the operation of steam plants in combination with moderate- or low-priced fuels, has brought steam-power-plant operation to the point where in some cases it is economically the equal of, or superior to, hydro-generated power. While this condition has resulted largely from the fact that cheap water powers are becoming increasingly more difficult to find, it has also had the effect of introducing intensive economic studies as to the relationship and relative value of steam- and water-generated power.

A number of studies by outstanding engineers have been published upon this subject during the past year under the auspices of The American Society of Mechanical Engineers; The Franklin Institute, Philadelphia; and The National Electric Light Association and its Pacific Coast affiliate, The Pacific Coast Electrical Association. A. H. Markwart, vice-president in charge of engineering of the Pacific Gas & Electric Co. of San Francisco, is the originator of an outstanding method for studying and properly evaluating the relative uses of steam and hydro power. It is the opinion of all students of the subject that the position of hydro power is economically difficult. Under the analytical method of Mr. Markwart, however, it becomes immediately clear that with certain relations between the capital cost of water power and fuel prices, although the cost of an all-hydro supply may be less than the cost of an all-steam supply, the cost of a combined hydro and steam supply is even less than the cost of an all-hydro supply; and conversely, with certain other relations, although the cost of an all-steam supply may be less than the cost of an all-hydro supply, the cost of a combined steam and hydro supply will be less than the cost of an all-steam supply. The practical application of these facts is apparent both East and West, and water-power developments are being examined from an enlightened economic viewpoint. A marked example of this is present in the U.G.I. installation at Rocky River, Connecticut. Eight thousand-horsepower vertical pumps have been installed for the utilization of off-peak power to elevate water to a storage reservoir for use in peak-load service. By this means a better balance of output is secured and a greater operating economy results. Although this plan of operation was used on a small scale very nearly twenty years ago in California and is quite generally used abroad, the U.G.I. installation is notable as being the first of such magnitude in this country.

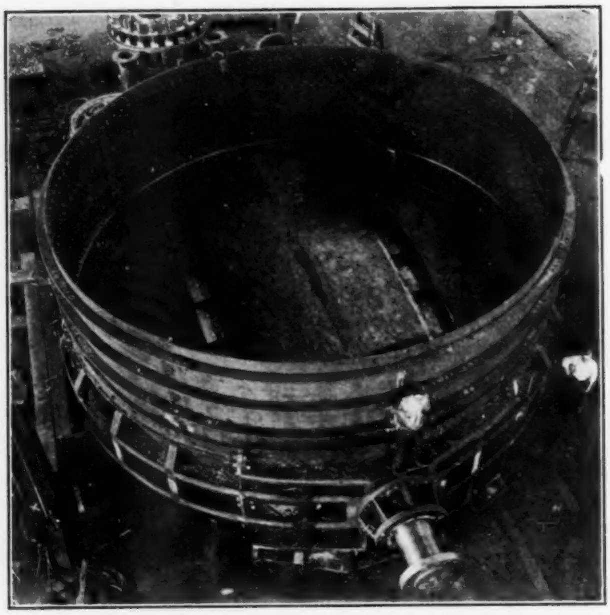
It is very evident also that the economic position of hydro power is well understood and appreciated by the manufacturers of hydraulic-power machinery. Numerous studies in the engineering departments, laboratories, and in the field are being made by the leading manufacturers for the purpose of securing increased economy in hydro-power machinery. Results of this work will continue to be of untold benefit to industry and to the country as a whole. Work of this sort is, however, deplorably handicapped by failure on the part of a large number of central-power or public-utility companies to appreciate that the funds for carrying on such work must come from and be included in the sale of the machinery they purchase. Despite the fact that the prices obtainable by manufacturers for hydraulic-power machinery have been extremely poor, an effort has nevertheless been made to carry on their research and economic studies. Much greater advance would undoubtedly be made, however, and greater benefit will inevitably result, if some plan may be worked out between the purchasers and the manufacturers under which the manufacturers may be placed in funds as a result of their industry, with which to carry on their efforts upon a major scale. An exceptional few of the utility companies have practiced this policy, and no doubt know that the results secured have been ample recompense.

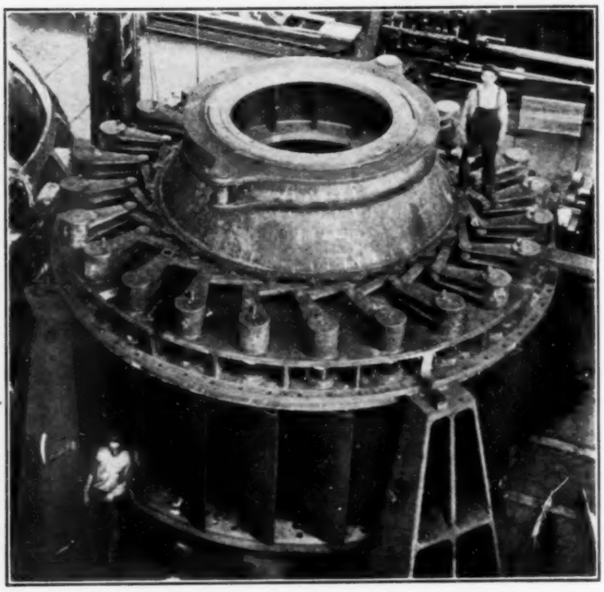
The administration and regulation of our water-power resources by the Federal Power Commission have been generally acceptable to the people and accepted by the public utilities. The introduction of discussion and agitation in some directions toward interstate regulation of large projects such as the St. Lawrence, Tennessee, and Colorado Rivers is apparent.

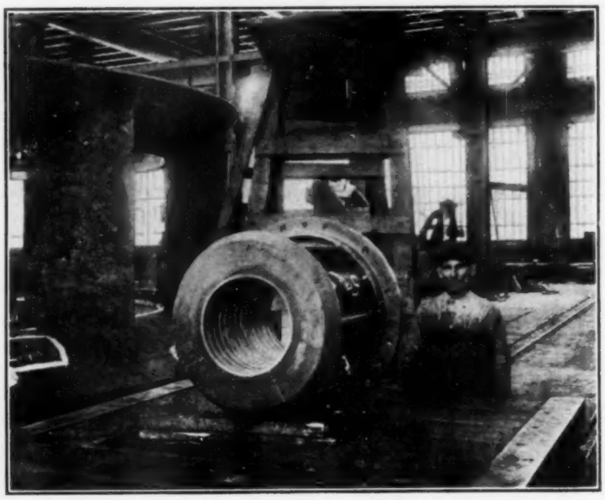
The discontinuance of some municipalities in the hydro-electric-power field is noted, and their activities continue in some other parts of the country, notably in Los Angeles and San Francisco.

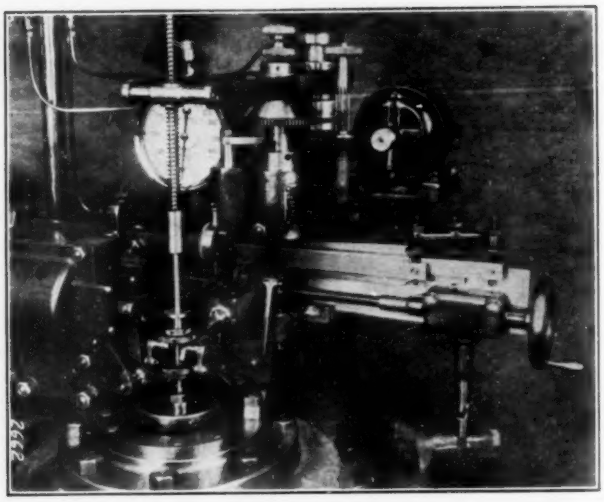
The findings in the so-called "Indianapolis Water Rate Case" are worthy of special mention. The Indianapolis Water Company, which is understood to be the third largest individual water company in the United States, brought suit to enjoin the Public Service Commission of Indiana, its members, and the City of Indianapolis from putting into force certain water rates on the ground that the fixed rates were confiscatory. The adjudication which followed and final decision which was rendered by the United States Supreme Court, November 22, 1926, is of special interest to the membership of the Hydraulic Division as it has set forth for the first time in the history of the United States Supreme Court definite principles having to do with the method of evaluating properties. The text of the entire decision is recommended to those who are further interested. The outstanding points, however, are contained in the following quotations from the majority opinion.

1 In determining present value, consideration must be given to prices and wages prevailing at the time of the investigation, and in









Above: Shop Assembly of 27-Ft. Pivot Valve, Conowingo Development

Below: Rubber-Lined Guide Bearing for 5000-Hp. Turbine

Above: Shop Assembly of 54,000-Hp. Turbine for Conowingo Development

Below: Automatic Control Features Provided for 17,000-Hp. Pelton Wheel

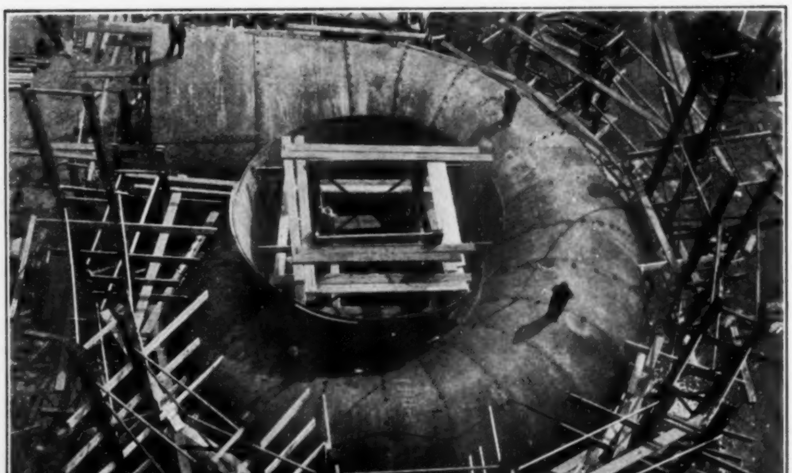


Plate-Steel Volute Casing for 54,000-Hp. Turbine, Conowingo Development

the light of all the circumstances there must be an honest and intelligent forecast as to the probable price and wage levels during a reasonable period in the immediate future.

2 Re depreciation: The testimony of competent valuation engineers who have examined the property and made estimates in respect of its condition is to be preferred to mere calculations based on averages and assumed probabilities.

3 A reasonable rate of return is not less than seven per cent.

The opinion emphasizes also the necessity of including value of water rights, going-concern value, and working capital in a proper evaluation. Although it has been customary for some years for experts to give testimony of their own conclusions as to the proper rate or percentage of depreciation to be deducted in evaluation cases, such conclusions being based upon actual inspection by the experts themselves, it is believed that no former opinion has so emphasized the justice of this method. Because of the clarification of the entire matter of evaluations as a result of the opinion, it has been deemed advisable to make special mention of the case so that those further interested may secure the entire text for further study.

Substantially cognate questions are involved in the recent decisions in the Kansas City Gas Co. case and the still more interesting case of the St. Louis & O'Fallon Railroad Co. The entire matter is so important that there is no doubt that it will come, and probably within not too long a time, before the U. S. Supreme Court.

### Improvements in Hydro-Power Machinery

A review of the year's progress does not bring special emphasis upon any outstanding mechanical improvement in hydro machinery. Intensive study has, however, been given to the improvement of existing designs in which advantage has been taken of operating experience. Knowledge of the comparative remoteness of remaining undeveloped hydro-power sites and their consequent high cost of development has given direction of thought among leaders of the industry to the necessity for simplification and economy of operation in hydroelectric installations. It is recognized that economy of plant operation is best secured with equipment which will operate most continuously and with the least expenditure for maintenance and renewals. To increase the existing knowledge, intensive studies are being made of the operation of power plants both steam and hydroelectric.

The outages of plants (or units), their causes, maintenance, and operating costs are being scrutinized and their relation to first cost of apparatus determined. In hydroelectric plants the economy of water consumption is receiving first attention. Air is being introduced into turbines automatically and otherwise, with the result that their no-load efficiency has been increased to a great extent when generators are floated on the line for the improvement of power factor. This method of operation has received much attention and its development has resulted in the elimination of a large percentage of stand-by leakage through turbines. It has become almost universal practice to make accurate tests of water wheels and turbines after installation to determine their operating characteristics. Information secured as a result of these tests is used to great advantage in developing the most economical method of plant operation in connected systems, the hydraulic conditions also being considered.

Voltages and frequencies are undergoing gradual standardization. This work must lead that of further and future interconnections.

The flow of streams that are subject to wide seasonal variations is being utilized to increased advantage by adding induced capacity to hydraulic turbines by means of backwater suppressors and ejector turbines. A great deal of attention is being paid to the improvement of turbine operation under variable heads. This problem has been more actively met in the European plants than in the United States, and instances of notable results secured have been published in the technical press. The most promising results have been secured in obtaining high efficiencies over widely varying heads by means of turbines having adjustable-bladed runners operated independently and in some cases automatically.

Propeller-type turbines are being successfully operated with stability and good regulation under increasingly higher heads, and efficiencies are ranging upward to ninety-two and ninety-three per cent.

Development of the use of rubber in various places is continued. Experience is increasing in the use of rubber seal rings for turbine runners. Rubber seals have been introduced as a means for decreasing the leakage around guide vanes when in closed position for the purpose of decreasing shutdown losses. Rubber is being applied to the periphery of large butterfly valves, and marked success is being secured in decreasing of water leakage by this method. Several cases are on record in which water-lubricated rubber bearings have been used with great success in turbines. Bearings of this type have replaced lignum vitae, with much better wearing results.

Much is being done to eliminate outage of hydroelectric plants from failure of the governor driving belt. Development in this direction is being manifest in the operation of the centrifugal elements of the governors by means of direct gear connection and electric motor. Other designs provide for mounting the centrifugal element directly upon the shaft of the prime mover.

Spiral casings for turbines which operate under moderate heads are being made of plate steel, with the joints in some cases being electric-welded in place at point of installation as means of securing more permanent water-tightness than by calking.

As a means of maintaining the turbine runner in its exactly central position, a hemispherical combined thrust and turbine guide bearing to the design of Albert Kingsbury may shortly be tried.

A measure of economy and increased reliability is being manifested in the electric welding of plate steel and rolled structural-steel forms into the frames or stators of large generators for which castings of iron or steel have been hitherto used almost exclusively.

Means for maintaining a perpetual check upon hydroelectric-power-plant operation, both electrically and hydraulically, are being permanently installed in the power plants and are rapidly proving their value as an aid to the maintenance of the best operating efficiencies at all times.

The value of full automatic and semi-automatic operation of water-power plants is assured, and a great economy has been effected by their use. As a result, smaller water-power sources hitherto undeveloped or found to be very expensive to operate are being brought into service upon an economical basis.

### Other Improvements in Hydroelectric-Plant Construction

Of the improvements in hydroelectric-plant construction other than those which have taken place within the power house itself, several developments are worthy of special mention. The so-called "Johnson-Wahlmann intake" for admitting water into conduits is being installed. Its use is of special advantage in the avoidance of ice troubles at the intake and diversion works.

For high-head developments where the purpose of finding a suitable and safe penstock construction at reasonable cost has been a particularly vexing one, a solution has apparently been found in the development of centrifugally cast and cross-roll-forged seamless steel piping. The installation of expensive plant machinery for the manufacture of this pipe of high-grade steel in sizes from thirty-two inches up to any diameter which may be

shipped, and in thicknesses varying from one-half inch up to five or even six inches, is assured and will undoubtedly mean much to the economic possibility of installing high-capacity, high-head, hydroelectric power plants.

In the case of tunnels lined with concrete a most important development has been that of the Hackley pneumatic apparatus for forcing concrete behind the forms of tunnels. This apparatus deposits the concrete without segregation and in horizontal layers in a very effective manner, up to and including even the crowns of the arches.

The fact that 220,000-volt transmission is now a demonstrated success as to reliability and economy, will undoubtedly mean much in the development of water-power projects which have hitherto been considered not economically accessible. Crest gates are being increasingly used as a means of maintaining the most economical hydraulic conditions for plant operation.

There has been wide development in the use of Johnson needle valves as an economical means for stream and storage-reservoir regulation. Valves of this type are becoming the accepted standard in this service.

### The Broader Possibilities of Economic Hydroelectric-Plant Construction

In the light of the present advanced state of the art there is no doubt that there are numerous old plants operating in systems and under comparatively ancient water-power concessions that can well afford to be rebuilt or modernized. A study of such possibilities will in numerous cases prove to offer a handsome return upon the capital investment required. Another, and probably the source of the greatest opportunity for economic hydraulic power, lies in the complete and balanced development of entire streams and watersheds into a single project. There are probably numerous cases where the existence of isolated power developments has served to distract attention from the possibilities of a river or watershed which would be readily apparent if existing developments were removed from the picture. An effort should be made to uncover these and analyze their possibilities in the light of present-day knowledge.

### Research

Research in the field of hydraulics is continuing in many directions. One of the outstanding projects in this respect is the Stevenson arch-dam investigation. This consists of an elaborate test upon a full-sized model arch dam made of concrete and having a height of approximately sixty feet, a thickness near the crest of about two feet, and a length at the crest of one hundred and sixty-five feet. This dam has been installed on Stevenson Creek, California, on the system of the Southern California Edison Co., under conditions comparable to those met in actual installations, and has been provided with means for scientific observations. The knowledge gained is already proving of great benefit. The work is being done under the auspices of the Engineering Foundation and is assisted by a notable group of contributors and cooperators, including the United States Bureau of Standards.

Research with the aid of small-scale models is increasing, and there are many notable examples of this, such as the Niagara Falls Power Co. model for the investigation of the proposed remedial works for the preservation and improvement of the scenic grandeur of Niagara Falls with the possibility of diverting more water for power purposes; the Chelan dam development of the Washington Water Power Co.; and the observation of surge-chamber phenomena at the Pit No. 3 development of the Pacific Gas & Electric Co. The Niagara Falls Company has undertaken extensive research in connection with its operations for the purpose of determining the friction losses in large concrete-lined tunnels.

Research is also being carried on for the enlargement of knowledge for the purpose of intake design; draft-tube construction; the determination of spiral or scroll-case forms for turbines; enlargement of the knowledge of causes of turbine-runner pitting, and many other live subjects.

A very constructive work has been done by Ray S. Quick in his analysis entitled "Comparison and Limitations of Various Water-Hammer Theories." The complete text of Mr. Quick's paper was read at the Spring Meeting of The American Society of Mechanical Engineers at White Sulphur Springs, West Virginia, in May, 1927.

A matter in which there is still much to be done is the investigation of the causes of corrosion in penstocks. It is hoped that this will receive greater attention than it has in the past.

### Conclusion

The field of hydroelectric power is one of great promise and intense interest. The development of the market for electricity exhibits a healthy and encouraging increase. Activity in the works of irrigation and reclamation not only provides a market for electricity, but offers an inviting field to the builders of water-regulating and pumping equipments. There is vast opportunity for the users of hydraulic machinery of all kinds to co-operate with its builders and for the development of a purchasing policy which will give full recognition to the fact that the interests, aims, and desires of all are closely related. More complete realization of these mutual interests will inevitably lead to the greater progress for which we are all striving.

Ely C. Hutchinson, *Chairman.*

# A New Method of Separating the Hydraulic Losses in a Centrifugal Pump

## Particulars of a Method by Means of Which the Friction and Shock Losses of a Given Pump May Be Determined Separately from Its Head-Capacity Curve, Together with Illustrative Example

By MICHAEL D. AISENSTEIN,[1] BERKELEY, CALIF.

The so-called hydraulic losses in a centrifugal pump are composed of friction losses and shock loss. The friction losses are those which are due to resistance offered to the water by the walls of the runner and case. The shock loss may be considered as due to the sudden enlargement of passages.

It is important for the designer to know how the losses are distributed and to have a method of separating them, so that by studying the variation of these losses he may decide in which direction improvement should progress.

The purpose of this paper is to present a method by means of which these losses may be determined separately from the head-capacity curve of a given centrifugal pump.

The following symbols and nomenclature are used:

$d_1$ = diameter at inlet of impeller in feet
$d_2$ = diameter at outlet of impeller in feet
$k$ = coefficient of head loss
$c_1$ = absolute velocity of water at entrance of impeller, feet per second
$c_2$ = absolute velocity of water at exit of impeller, feet per second
$w_1$ = relative velocity of water at inlet of impeller, feet per second
$w_2$ = relative velocity of water at outlet of impeller, feet per second
$v_d$ = velocity in volute case referred to $d_2$, feet per second
$\omega$ = angular velocity in radians
$T$ = torque in foot-pounds
$L$ = power in foot-pounds per second
$M$ = moment of momentum
$u_1$ = peripheral velocity of impeller at inlet, feet per second
$u_2$ = peripheral velocity of impeller at exit, feet per second
$a$ = area in square feet
$t$ = vane thickness at periphery in feet
$z$ = number of vanes
$\delta$ = vane angle (fixed)
$\theta$ = water angle
$b_1$ = breadth between the impeller disks or shrouds at the diameter $d_1$ in feet
$b_2$ = breadth between the impeller disks or shrouds at the diameter $d_2$ in feet
$\gamma$ = weight of 1 cubic foot of water
$Q$ = capacity in cubic feet per second
$h$ = head in feet
$H$ = theoretical head in feet for an impeller with a finite number of vanes
$H_{\text{inf.}}$ = theoretical head in feet for an impeller with an infinite number of vanes.

Let $T$ = torque exerted on the impeller. Then, neglecting the losses,

Torque = change in the moment of momentum

$$T = \Delta M$$

or

$$T = \frac{Q\gamma}{g}(r_2c_2\cos\theta_2 - r_1c_1\cos\theta_1) \qquad [1]$$

Calling

$$c_2\cos\theta_2 = c_{u2}$$

and

$$c_1\cos\theta_1 = c_{u1}$$

Equation [1] can be rewritten as

$$T = \frac{Q\gamma}{g}(r_2c_{u2} - r_1c_{u1}) \qquad [2]$$

This is the torque given to the water by the shaft. Multiplying both sides of Equation [2] by the angular velocity $\omega$,

$$T\omega = \frac{Q\gamma}{g}(r_2\omega c_{u2} - r_1\omega c_{u1})$$

or since

$$T\omega = L = \text{power}, \quad r_2\omega = u_2, \quad \text{and } r_1\omega = u_1,$$

$$L = \frac{Q\gamma}{g}(u_2c_{u2} - u_1c_{u1}) \qquad [3]$$

The power is also equal to the weight of the fluid raised per second against the head $H$, so that

$$L = Q\gamma H \qquad [4]$$

Equating Equations [3] and [4],

$$Q\gamma H = \frac{Q\gamma}{g}(u_2c_{u2} - u_1c_{u1})$$

or

$$H = \frac{u_2c_{u2} - u_1c_{u1}}{g} \qquad [5]$$

which is the fundamental equation of a centrifugal pump.

The losses in a centrifugal pump may be classified as

*a* Friction losses and
*b* Shock loss.

The friction losses are approximately proportional to the square of the capacity and may be expressed as

$$h_f = CQ^2 \qquad [6]$$

The shock loss, which is due to the sudden enlargement of passages, may be represented by

$$h_s = \frac{k_s(c_{u2} - v_d)^2}{2g} \qquad [7]$$

---

[1] Hydraulic Engineer, Byron Jackson Pump Mfg. Co. Jun. A.S.M.E.

Contributed by the Hydraulic Division and presented at the Annual Meeting, New York, December 5 to 8, 1927, of The American Society of Mechanical Engineers. All papers are subject to revision.

and the actual head produced by the pump will be

$$h = H - h_f - h_s$$

$$= \frac{u_2 c_{u2} - u_1 c_{u1}}{g} - CQ^2 - \frac{k_s(c_{u2} - v_d)^2}{2g} \quad \ldots\ldots [8]$$

But

$$c_{u2} = u_2 - \frac{c_{r2}}{\tan \delta_2} \quad \ldots\ldots [9]$$

and

$$c_{u1} = u_1 - \frac{c_{r1}}{\tan \delta_1} \quad \ldots\ldots [10]$$

also

$$c_{r2} = \frac{Q}{(\pi d_2 - z t_2)\, b_2} \quad \ldots\ldots [11]$$

and

$$c_{r1} = \frac{Q}{(\pi d_1 - z t_1)\, b_1} \quad \ldots\ldots [12]$$

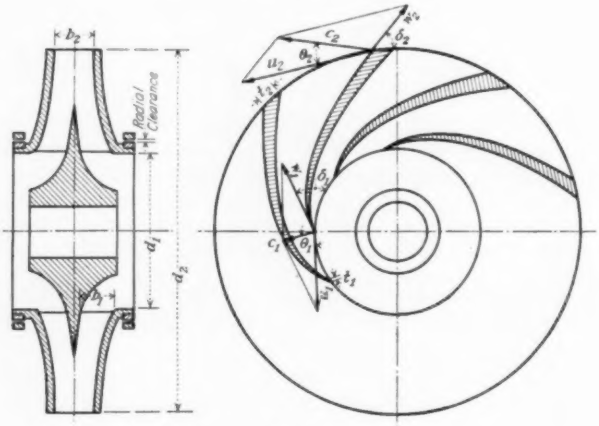



Fig. 1

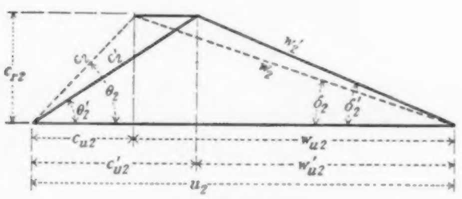


Fig. 2

Substituting Equations [9] to [12] in Equation [8] and remembering that $v_d = Q/a_3$, where $a_3 = a_3' \, d_2/d_3'$,

$$h = \frac{u_2^2 - \dfrac{u_2}{(\pi d_2 - z t_2) b_2 \tan \delta_2} Q - u_1^2 + \dfrac{u_1}{(\pi d_1 - z t_1) b_1 \tan \delta_1} Q}{g}$$

$$- CQ^2 - \frac{k_s \left[ u_2 - \dfrac{Q}{(\pi d_2 - z t_2)\, b_2 \tan \delta_2} - \dfrac{Q}{a_3} \right]^2}{2g} \quad \ldots\ldots [13]$$

or

$$h = \left[ \frac{u_2^2 - u_1^2}{g} \right] + \left[ \frac{\dfrac{u_1}{(\pi d_1 - z t_1) b_1 \tan \delta_1} - \dfrac{u_2}{(\pi d_2 - z t_2) b_2 \tan \delta_2}}{g} \right] Q$$

$$- CQ^2 - \left[ \frac{\sqrt{k_s}}{\sqrt{2g}} u_2 - \frac{\sqrt{k_s}}{\sqrt{2g}} \left\{ \frac{1}{(\pi d_2 - z t_2) b_2 \tan \delta_2} + \frac{1}{a_3} \right\} Q \right]^2 \quad \ldots\ldots [14]$$

For a given pump running at a constant speed, all the bracketed quantities in Equation [14] are constant as they depend on the physical dimensions of pump; therefore we may write

$$h = A + BQ - CQ^2 - (D - EQ)^2 \quad \ldots\ldots [15]$$

where $CQ^2$ is the friction loss and $(D - EQ)^2$ is the shock loss, and

$$A = \frac{u_2^2 - u_1^2}{g} \quad \ldots\ldots [16]$$

$$B = \frac{\dfrac{u_1}{(\pi d_1 - z t_1) b_1 \tan \delta_1} - \dfrac{u_2}{(\pi d_2 - z t_2) b_2 \tan \delta_2}}{g} \quad \ldots\ldots [17]$$

$$D = \sqrt{\frac{k_s}{2g}} \times u_2 \quad \ldots\ldots [18]$$

$$E = \frac{k_s}{2g} \left\{ \frac{1}{(\pi d_2 - z t_2) b_2 \tan \delta_2} - \frac{1}{a_3} \right\} \quad \ldots\ldots [19]$$

Expanding Equation [15],

$$h = A + BQ - CQ^2 - D^2 + 2DEQ - E^2Q^2$$

or

$$h = (A - D^2) + (B + 2DE)Q - (C + E^2)Q^2 \quad \ldots\ldots [20]$$

and calling $A - D^2 = A'$, $B + 2DE = B'$, and $C + E^2 = C'$,

$$h = A' + B'Q - C'Q^2 \quad \ldots\ldots [21]$$

The constants $A'$, $B'$, and $C'$ can be determined from an actual head-capacity curve, as will be shown later in an example, and as above stated,

$$A' = A - D^2 \quad \ldots\ldots [22]$$

$$B' = B + 2DE \quad \ldots\ldots [23]$$

$$C' = C + E^2 \quad \ldots\ldots [24]$$

The theoretical head when computed by means of Equation [5] is always higher than the actual theoretical head:

$$H = h + \text{losses} \quad \ldots\ldots [25]$$

Referring to Fig. 2, because the number of vanes is finite the particles of water do not follow the vane angle $\delta_2'$ but follow a certain average angle $\delta_2$ which is smaller than $\delta_2'$. Consequently $c_{u2}$ is less than $c'_{u2}$, and if the theoretical head with an infinite number of vanes is

$$H_{\text{inf.}} = \frac{u_2 c'_{u2} - u_1 c_{u1}}{g} \quad \ldots\ldots [26]$$

the theoretical head with finite number of vanes is

$$H = \frac{u_2 c_{u2} - u_1 c_{u1}}{g}$$

Hence Equation [17] cannot be used in this form unless the angle $\delta_2$ is corrected.

Since the maximum efficiency occurs practically at a point where the hydraulic losses are minimum, that is, where the sum of the friction losses and shock loss is a minimum,

$$Y = CQ^2 + (D - EQ)^2 = \text{minimum} \quad \ldots\ldots [27]$$

The value of $Q$ which makes $Y$ a minimum must satisfy the condition $dY/dQ = 0$; hence, differentiating Equation [27] with respect to $Q$ and equating it to zero,

$$2CQ + 2(D - EQ)(-E) = 0$$

or

$$CQ - DE + E^2Q = 0 \quad \ldots\ldots [28]$$

From Equation [24]

$$C = C' - E^2$$

Substituting this value of $C$ in [28]

$$C'Q - E^2Q - DE + E^2Q = 0$$

or

$$C'Q = DE \ldots\ldots\ldots\ldots\ldots\ldots\ldots [29]$$

where $Q$ is the rate of discharge at the point of maximum efficiency.

We now have five equations, [16], [22], [23], [24], and [29] and five unknowns $A$, $B$, $C$, $D$, and $E$. Hence from given characteristics obtained from an actual test it is possible by simple substitution of different values of $Q$ to determine the friction losses $CQ^2$ and the shock loss $(D - EQ)^2$. An example illustrative of the use of these equations follows.

### Illustrative Example

Let Fig. 3 represent an actual test of a 5-in. double-suction single-stage centrifugal pump running at 1750 r.p.m. The inlet

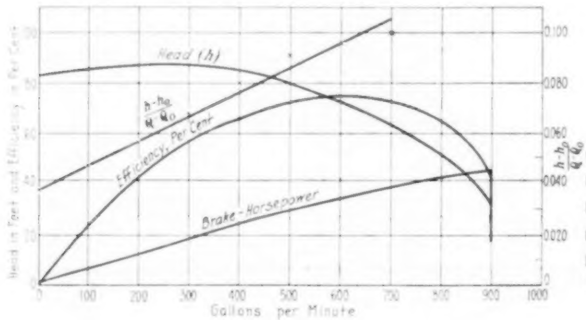



Fig. 3

diameter of the impeller $d_1 = 4^3/_8$ in., and the outlet diameter $d_2 = 9$ in.

Let us tabulate the values of $Q$ and corresponding values of $h$ from Fig. 3 as in Table 1.

TABLE 1

| No. | $Q$, g.p.m. | $h$, ft. | $Q - Q_0$ | $h - h_0$ | $\frac{h - h_0}{Q - Q_0}$ | $h'$ | $\Delta h$ |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 83 | −800 | 30 | −0.0375 | 83.2 | −0.2 |
| 2 | 100 | 86 | −700 | 33 | −0.0471 | 86 | 0 |
| 3 | 200 | 87 | −600 | 34 | −0.0566 | 87.3 | −0.3 |
| 4 | 300 | 87 | −500 | 34 | −0.0680 | 86.5 | +0.5 |
| 5 | 400 | 85 | −400 | 32 | −0.0800 | 83.8 | +1.2 |
| 6 | 500 | 80 | −300 | 27 | −0.0900 | 79 | +1.0 |
| 7 | 600 | 72 | −200 | 19 | −0.0950 | 72.2 | −0.2 |
| 8 | 700 | 63 | −100 | 10 | −0.1000 | 63.5 | −0.5 |
| 9 | 800 | 53 | 0 | 0 | ..... | 53.1 | −0.1 |

The points $\left[Q, \frac{h - h_0}{Q - Q_0}\right]$ when plotted lie on a straight line (see Fig. 3), which means that these data fit an equation of the form

$$h = A' + B'Q - C'Q^2$$

Using the method of averages and dividing the data into two groups 1, 2, 3, 4 and 5, 6, 7, 8 and adding the $Q$'s and $\frac{h - h_0}{Q - Q_0}$'s for each group, we get

$$4a + 600b = -0.2092$$

$$4a + 2200b = -0.3650$$

Solving for $a$ and $b$,

$$b = -0.973 \times 10^{-4}$$

$$a = -0.0377$$

Substituting these values in

$$\frac{h - h_0}{Q - Q_0} = a + bQ$$

we obtain

$$\frac{h - 53}{Q - 800} = -0.0377 - 0.973 \times 10^{-4}Q$$

Solving this equation for $h$,

$$h = 83.2 + 0.0401Q - 0.973 \times 10^{-4} Q^2$$

This equation is in the form

$$h = A' + B'Q - C'Q^2$$

Substituting different values of $Q$ in gallons per minute, we obtain $h'$ and $\Delta h$, which are tabulated in Table 1.

Next let us determine the constants in Equation [15], having found above that

$$A' = 83.2,\ B' = 0.0401,\ \text{and}\ C' = 0.973 \times 10^{-4}.$$

From Equation [16]

$$A = \frac{u_2^2 - u_1^2}{g}$$

and since from the data given,

$$u_2 = \frac{1750 \times \pi \times 9^1/_2}{720} = 72.4 \text{ ft. per sec.}$$

$$u_1 = \frac{1750 \times \pi \times 4^3/_8}{720} = 33.3 \text{ ft. per sec.}$$

$$A = \frac{72.4^2 - 33.3^2}{g} = 128$$

Solving Equation [22] for $D$,

$$D = \sqrt{A - A'} = \sqrt{128 - 83.2} = 6.7$$

Solving Equation [29] for $E$,

$$E = \frac{C'Q}{D}$$

At the point of maximum efficiency the pump is delivering 600 gal. per min., therefore

$$E = \frac{0.973 \times 10^{-4} \times 600}{6.7} = 0.00872$$

From Equation [24],

$$C = C' - E^2$$
$$= 0.973 \times 10^{-4} - 0.00872^2 = 0.213 \times 10^{-4}$$

From Equation [23]

$$B = B' - 2DE$$
$$= 0.0401 - 2 \times 6.7 \times 0.00872 = -0.0771$$

Substituting all numerical values of coefficients in Equation [15],

$$h = (128 - 0.0771Q) - \underbrace{0.213 \times 10^{-4}Q^2}_{\text{friction}} - \underbrace{(6.7 - 0.00872Q)^2}_{\text{shock}}$$

After $h_f$ and $h_s$ are determined it is possible to calculate the theoretical $H$ (no-loss head) and the hydraulic efficiency $\eta_h$.

$$H = h + h_f + h_s$$

$$\eta_h = \frac{h}{h + h_f + h_s}$$

These results are tabulated in Table 2 and plotted below in Fig. 4.

TABLE 2

| $Q$, gal. per min. | $h$, ft. | $h_f$, ft. $0.213 \times 10^{-4} Q^2$ | $h_s$, ft. $(6.7 - 0.00872Q)^2$ | $H$, ft. $h_f + h_s + h$ | $\eta_h$ per cent |
|---|---|---|---|---|---|
| 0 | 83 | 0 | 45 | 128 | 64.9 |
| 100 | 86 | 0.2 | 33.6 | 119.8 | 71.7 |
| 200 | 87 | 0.8 | 25 | 112.8 | 77.2 |
| 300 | 87 | 1.9 | 16.8 | 105.7 | 82.3 |
| 400 | 85 | 3.4 | 10.2 | 98.6 | 86 |
| 500 | 80 | 5.3 | 5.3 | 90.6 | 88.2 |
| 600 | 72 | 7.7 | 2.1 | 82.0 | 88.0 |
| 700 | 63 | 10.4 | 0.4 | 73.8 | 85.2 |
| 800 | 53 | 13.6 | 0.1 | 66.7 | 79.5 |
| 900 | .. | 17.2 | 1.2 | ... | ... |
| 1000 | .. | 21.3 | 4.1 | ... | ... |

Analyzing the $h_f$ and $h_s$ losses in Fig. 4, it is seen that the shock loss reaches its minimum value at about 750 gal. per min. This is an indication that the casing of the pump is a little too large. By reducing the areas of the volute casing the point of zero shock loss could be shifted toward the left and the efficiency could probably be improved if the increase in friction loss due to reduction of the casing areas would not offset the decrease in shock loss.

In conclusion, the author would like to point out that many writers on centrifugal pumps define the hydraulic efficiency of a pump as the ratio

$$n_h = \frac{h}{H_{\text{inf.}}}$$

and that the value of the hydraulic efficiency obtained by means of this formula is often less than the actual pump efficiency,

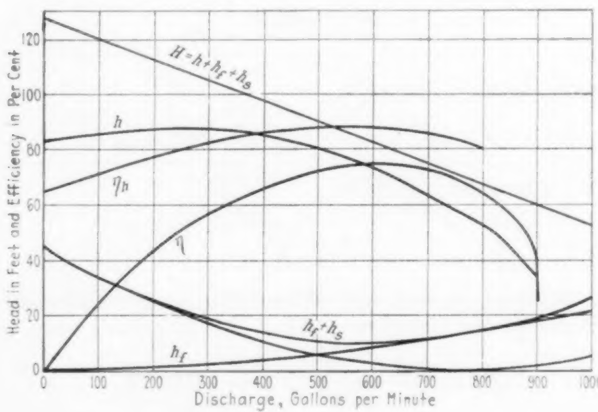



FIG. 4

which includes besides hydraulic losses mechanical losses such as disk friction, friction in stuffing boxes, etc.

The reason for this inconsistency is self-evident when one takes in consideration the fact that $H_{\text{inf.}}$ is never produced by the impeller and is an imaginary quantity because, as was explained, the average actual angle between the relative velocity $w_2$ and peripheral velocity $u_2$ is always less than the casting angle of the vane. Hence the drop from $H_{\text{inf.}}$ to $H$ does not consume any power and is not a loss.

To discuss the factors which influence this "no loss" drop from $H_{\text{inf.}}$ to $H$, the shock and friction losses, is beyond the scope of this paper.

## Discussion

Robert W. Angus.[2] The paper presents an interesting problem on the centrifugal pump, and one to which little attention has recently been paid. Earlier writers on centrifugal pumps went into the distribution of the losses with much care and some interesting discussion of the question will be found in the paper by Unwin in Minutes of the Institution of Mechanical Engineers, vol. 53, and there is a more complete discussion in a book on centrifugal pumps by C. H. Innes.

Innes deals with various cases, discusses the losses at exit due to proper and improper design of the volute, and determines the best velocity in the latter. He further deals with the diffuser

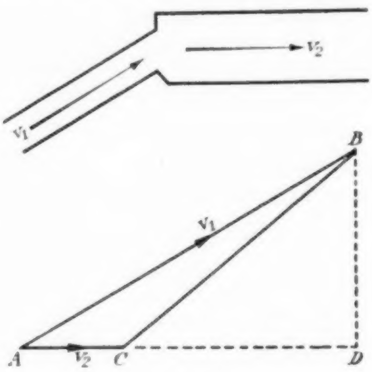



FIG. 5

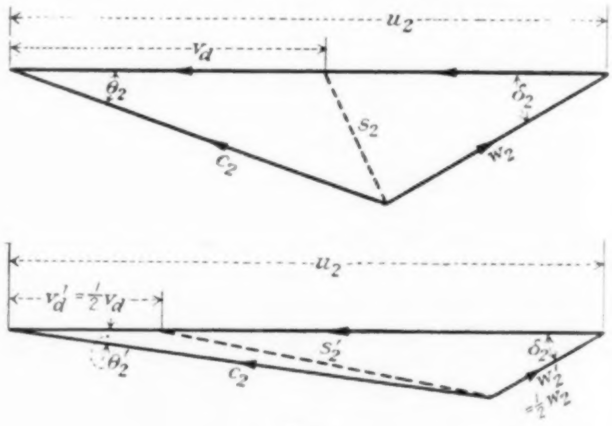



FIG. 6

or radial space frequently left between the rim of the impeller and the inside of the volute in the older pumps.

The author states that the friction losses are proportional to the square of the discharge. This statement is rather questionable when one considers the range of discharges with which the author deals. For small ranges of velocity a coefficient $c$ may be determined so that $h_f = cQ^2$, but such a law is far from true if there is much variation in the discharge. For example, in a 12-in. pipe the Hazen and Williams tables give the loss per 1000 ft. of old pipe, with a velocity of 1.97 ft. per sec., as 2.10 ft. and for a velocity of 10.84 ft. per sec. the loss is 49.4 ft.; the value of $h_f/v^2$ being 0.54 for the first case and 0.42 for the second case, a difference too great to neglect.

The expression for the loss of head due to shock as given in Equation [7] appears to the writer to be inaccurate. It has

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been established as a general theorem that when water with velocity $v_1$ in a small pipe passes abruptly into a larger pipe where the velocity is $v_2$, the two pipes being in line, the loss of head is proportional to $(v_1 - v_2)^2$. In the case of pipes not in line as shown in Fig. 5, the loss is proportional to the vector difference between $v_1$ and $v_2$. Thus in the same figure $AB = v_1$, $AC = v_2$ and the loss of head is proportional to $(BC)^2$, or to the vector difference $(v_1 - v_2)^2$. The author assumes the loss of head due to shock to be proportional to $(AD)^2 - (AC)^2$ where $AD$ is the projection of $v_1$ on the direction of $v_2$. Regardless of which method is adopted, the coefficient $k_s$ cannot be regarded as constant. In King's "Handbook of Hydraulics" a table is given of values of the corresponding coefficient when the pipes

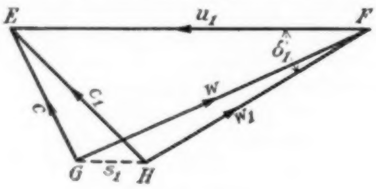


Fig. 7

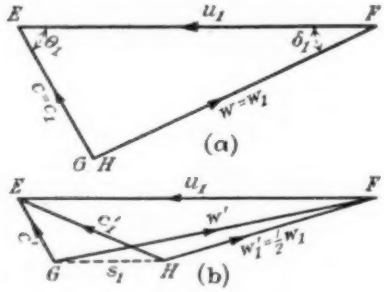


Fig. 8

are in line, which shows a variation of about 15 per cent when the velocity varies from 5 ft. per sec. to 40 ft. per sec.

Throughout the paper the author assumes constant speed, and the velocity triangles at exit from the impeller for two discharges, one equal to half of the other, are given in Fig. 6, the shock velocity being indicated by the letter $s_2$ and the loss due to shock being proportional to $s_2^2/2g$. It is quite possible to include an expression for $s_2^2/2g$ in the general pump theory which the author has given, although the resulting expression becomes somewhat cumbersome.

While the author has dealt with shock loss at exit from the impeller he has neglected entirely the corresponding loss at entry. The entry conditions are represented in Fig. 7 by the two triangles $EFG$ and $EFH$, the former representing the conditions just before entry and the latter the conditions just after entry. If the vanes are thin at this point, it is quite correct to draw $GH$ parallel to $EF$, but there is much uncertainty about the direction of $EG$, as the amount of whirl in the suction pipe is unknown. The letters are the same as the author's, and in this case the shock loss depends on the length of the line $GH = s_1$ and is proportional to $s_1^2/2g$.

If the designer knew the direction of $GE$ he would naturally make $G$ and $H$ coincide for the best efficiency, and this could be done for one discharge, but for all other discharges, at the same speed, $s_1$ is not zero. In Fig. 8 (*a*) shows the conditions for best efficiency and (*b*) the conditions for half the discharge corresponding to (*a*).

To make the theory complete, therefore, the two shock losses and the friction loss should be included, and as these are to be multiplied by coefficients which vary with the discharge, it would appear to be doubtful whether the analysis made by the author is reliable and can be made to furnish the information he desires. The author is, however, to be commended for returning to the early principles and bringing forward again the fundamental ideas on which the design of centrifugal pumps is based.

Some years ago the writer made a careful study of the same problem, introducing the expressions for the shock losses $s_1$ and $s_2$ mentioned in his discussion, and he found that the equation for the pump could be written in the form

$$AQ^2 + Bu_2Q + Cu_2^2 + 2gH = 0$$

where $A$ depends on the friction in the pump and also on the dimensions and angles, and $B$ and $C$ depend on the dimensions and angles only. If this equation is written so as to apply to a constant speed of operation,

$$AQ^2 + B'Q + C' + 2gH = 0$$

in which equation $H$ is the head against which the pump works. If the dimensions of the pump are available $B'$ and $C'$ may be readily determined, and the value of $A$ may be computed from different values of $Q$. Since $A$ includes the friction losses the latter may be determined.

The writer feels, however, that until there is greater certainty about the entry conditions and the action of the water in the impeller, these calculations cannot yield numerical results of much practical value.

The Author. Professor Angus, introducing an equation $AQ^2 + B'Q + C' + 2gH = 0$, claims that $AQ^2$ is the friction loss. This is not correct since $AQ^2$ includes part of the shock loss, which can be seen when following the derivation of Equation [21]. Consequently, the computed value of $A$ will be of no value. Moreover Professor Angus states that: "If the dimensions of a pump are available, $B'$ and $C'$ may be readily determined, and the value of $A$ may be computed from different values of $Q$." This statement is not correct since the actual angles which the water follows, as has been pointed out in the paper, are different from the casting angles of the impeller. For this very reason we have so much controversy about the validity of the different theories of the centrifugal pump. For the very same reason the author's method was introduced to avoid the use of the physical dimensions and angles which may lead, as every one who has dealt with centrifugal pumps knows, to preposterous results.

The shock loss at entrance due to thickness of the blades was not considered because the blades at the inlet of the impeller are usually sharpened and this loss becomes negligible. Innes, to whom Professor Angus refers, in "Centrifugal Pumps and Turbines," page 206, discussing Professor Unwin's analysis, says: "As he (Unwin) gives no vane thickness, it is probable he neglects that."

Another type of shock loss at entry is due to sudden change in direction of the absolute velocity and, as shown on page 193 of Innes' work, is equal to

$$h_s = \frac{c_{u1}^2}{2g}$$

This loss due to abrupt change of velocity would take place if directing vanes extending clear to the impeller tips were used. But modern practice to the author's knowledge no longer employs them.

Since water is set in rotation in the suction pipe there is no abrupt change in velocity for a relatively small discharge. For greater flows the rotation decreases and a certain amount of

loss at entrance may take place. But this, according to Daugherty's "Centrifugal Pumps," page 65, "does not seem to be of sufficient magnitude."

Hence the whole question of shock loss at the entry does not seem to be of great importance, especially as these relatively small losses if present will be included in the loss terms of Equation [15].

The treatment of the shock loss at the outlet of the impeller as presented by the author may be found in LeConte's "Hydraulics," Daugherty's "Centrifugal Pumps," and other treatises.

Water leaves the impeller with an absolute velocity $c_2$ which may be represented by two components, $c_{u2}$ (projection on the periphery) and $cr_2$ (radial component), and the expression for shock may be written as follows:

$$\frac{(c_{u2} - v_d)^2}{2g} + \frac{c_{r2}{}^2}{2g}$$

that is, the tangential component follows the law of sudden enlargement (difference in velocities squared) and the normal

From the principle of dynamic similarity we have for friction drop in circular pipes,

$$h_f = \frac{L}{d}\frac{v^2}{2g}\phi\left(\frac{vd}{\nu}\right) \qquad [30]$$

For streamline flow $\frac{vd}{\nu} < 2000$ and Equation [30] becomes

$$h_f = \frac{64}{2g}\frac{L}{d^2}v\nu \qquad [31]$$

For turbulent flow $\frac{vd}{\nu} > 3000$ Dr. Lee gives the following expression for the Stanton-Pannell curve:

$$\phi\left(\frac{vd}{\nu}\right) = 8\left[0.0765\left(\frac{\nu}{vd}\right)^{0.35} - 0.0009\right]$$

which substituted in Equation [30] gives

$$h_f = 8\left[0.0765\left(\frac{\nu}{vd}\right)^{0.35} - 0.0009\right]\frac{v^2}{2g}\frac{L}{d} \qquad [32]$$

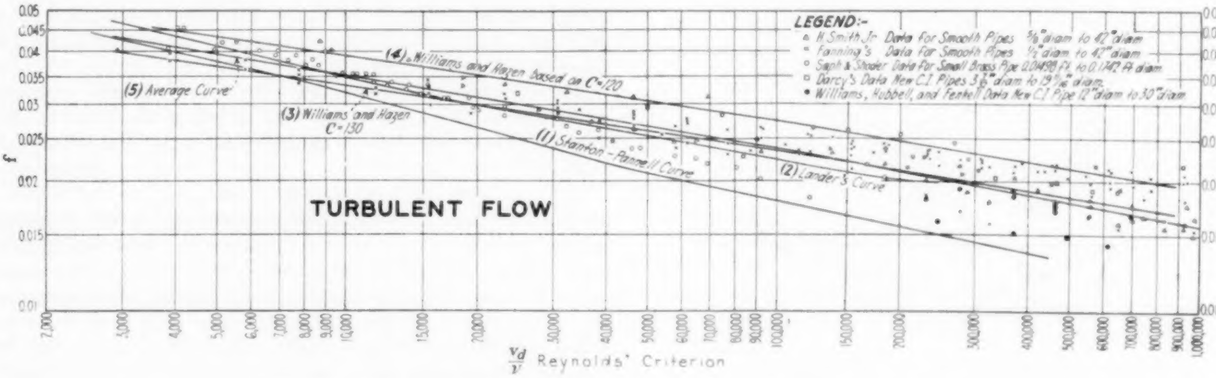


FIG. 9 RELATION BETWEEN $f$ AND $vd/\nu$ BASED ON EXPERIMENTAL DATA

component is wasted. The author when developing the expression for shock losses omitted the term $c_{r2}{}^2/2g$ purposely, since it appeared automatically in the friction term $CQ^2$ which included all losses following the law of variation of square of the velocity.

The table in King's "Handbook on Hydraulics" to which Professor Angus refers is based on experiments by H. W. Archer conducted in the hydraulic laboratory of the University of California. Professor LeConte of the same institution states in "Hydraulics," page 98: "Mr. H. W. Archer found that

$$h_s = 1.098\,\frac{(v_1 - v_2)^{1.919}}{2g}$$

though many experiments by the writer (LeConte) particularly at high velocities agree almost exactly with equation

$$h_s = \frac{(v_1 - v_2)^2}{2g},"$$

and since $K = I$, LeConte on page 99 states: "When a sudden enlargement exists in a pipe line the loss can be entered the energy equation by means of the expression

$$\frac{(v_1 - v_2)^2}{2g}$$

without the use of a coefficient $K$."

In general, in the case of a centrifugal-pump coefficient, $K$ appears to be less than unity, depending on the design of the pump in question.

where $d$ and $L$ are in feet, $v$ in feet per second, and $\nu$ is the kinematic viscosity in foot-poundal-second units.

It was noticed by the author that the values of $f$ — $(vd/\nu)$ as given by the Stanton-Pannell curve are somewhat low when used for commercially smooth pipes, and he therefore plotted values of $f$ against $vd/\nu$ for the turbulent flow from the data of various experimenters (Fig. 9), and drew his own average curve which satisfied an equation of the form:

$$\phi\left[\frac{vd}{\nu}\right] = \frac{0.167}{\left(\frac{vd}{\nu}\right)^{0.170}}$$

Substituting this in Equation [30],

$$h_f = 0.167\,\nu^{0.170}\,\frac{L}{d^{1.170}}\,\frac{v^{1.830}}{2g} \qquad [33]$$

This equation holds for any liquid flowing in a straight, commercially smooth circular pipe, and it may be noticed that no variable coefficient is introduced, since the coefficient and exponent are constant for any one type of surface.

The effect of roughness or curvature of the conduit, as indicated by various experiments, changes the slope of the $f$ — $vd/\nu$ curve, and consequently the method employed by Williams and Hazen in their tables in increasing the coefficient of friction to take care of roughness without the increase of the exponent, is incorrect.

Stanton, Gibson, Durand and others show that the roughness of a conduit increases the exponent $n$ of the Reynolds' formula

$$h_f = K \frac{v^n \nu^{2-n}}{d^{3-n}} L$$

Hence the case of the centrifugal pump with a revolving impeller having curved vanes and a volute casing could be approximated to that of a rough pipe, and the use of an exponent 2 with a constant coefficient similar to the Reynolds' equation was justified in opinion of the author.

Even if the exponent were less than 2 it would be higher than that in Williams and Hazen's formula, and the variation would be much smaller than claimed by Professor Angus.

On the other hand, assuming according to Professor Angus a 10 per cent variation in the coefficient of friction for half of the rated capacity, the friction loss for the above example (Table 2) at 300 gal. per min. would be $1.9 \times 0.90 = 1.71$, and the corresponding shock loss would be $16.80 + (0.10 \times 1.9) = 16.99$, a difference which could hardly be detected when plotted. The capacity on the right side of the point of maximum efficiency seldom extends farther than 50 to 75 per cent of the rated one, and consequently the variation would be negligible and in general much smaller than claimed by Professor Angus.

The real difficulties actually experienced by the author were due to excessive leakage and to "cut-off" phenomena, and he expected that among the discussions submitted there would be some comments on these points.

The leakage between the impeller and casing wear rings, if not excessive, can be taken care of by using two approximations and by moving the point of maximum hydraulic efficiency somewhat to the left from the point of maximum pump efficiency. If the results are still inconsistent, the influence of the short-circuit losses makes the analysis impossible unless the amount of leakage can be estimated.

By "cut-off" is meant a sudden drop in head, efficiency, and usually horsepower, which takes place when the inlet of the impeller becomes too small for a given flow and the pump becomes choked. No matter how wide the valve on the discharge of the pump is open, the capacity stays constant. It is evident that the equation of a parabola in the neighborhood of the "cut-off point" will not hold as a different law enters, and these points should be disregarded when determining the numerical values of Equation [21].

In conclusion, the author must state that this method of determining losses has been of great assistance in his practice. It has consistently indicated the correctly designed pumps and enabled him to reason out the cause of failure of pumps which otherwise could probably never be determined.

# A Method of Analyzing the Performance Curves of Centrifugal Pumps

## Development of Analytical and Graphical Methods of Determining Correction Factors from Test Curves for Use in Bringing Theoretical Pump Equations into Harmony with Practice

By JOSEPH LICHTENSTEIN,[1] ELIZABETH, N. J.

CENTRIFUGAL-PUMP practice still bases its calculations on the one-dimensional theory, which assumes a frictionless fluid flowing through an impeller with an infinite number of blades. It is evident that the results of this theory cannot well conform with actual practice where the number of blades is small, and where friction and a turbulent flow of water are encountered. Attempts to introduce a theory better adapted to the actual pump design have been made. Professor Lorenz has developed a two-dimensional theory (Neue Theorie and Berechnung der Schaufelrader), and Professor Prasil of Zurich has published a three-dimensional theory (Ueber Flüssigkeitsbewegungen in Rotationshohlraumen, *Schweizerische Bauzeitung*, 1923).

The pump designer rarely uses these theories. Not only because they are more complicated and not so general as the classical theory, being based on certain profiles which would limit the engineer in his designs, but especially because they are also based on a frictionless, non-turbulent flow, a supposition far from reality. The results obtained by employing these theories would therefore not be in correspondence with actual practice. It is therefore best to keep to the simple and most general, classical, one-dimensional theory, and to use it more as a guide indicating the general laws by which centrifugal pumps are governed, and with the understanding that its numerical results will have to be corrected by factors determined by means of actual experiences and tests. It is the deduction of these factors which is the task of this paper. Ordinarily the pump designer does not have the opportunity of measuring these factors directly, and besides, direct measurement, if not impossible, is at least very difficult. It will therefore be necessary to find an indirect method, using tests with which every pump manufacturer is familiar. These tests are the ordinary performance curves, capacity-head and brake-horsepower curves for constant speed.

### Correction Factors

It is also necessary before proceeding to decide what kind of factors are to be used in order to bring in correspondence theory and practice. Two values can always be brought into equality by multiplying one with a numerical correction factor. What the centrifugal-pump designer needs is a set of factors which are general and independent of the special design of pumps. This can only be the case if each factor is not merely a numerical value, but has a real physical meaning expressing the real reason for the difference between theory and practice. In the present study the author will use the following five correction factors which are to be deduced from the ordinary performance curves.

1 *Hydraulic Efficiency* is the ratio between the effective head and the total created head of the impeller. If we wish this hydraulic efficiency to be a physical reality, it is necessary that our theory shall really indicate the total created head of the actual pump. But we know that the equation of the total head in the one-dimensional theory indicates a far greater head than the actual pump creates. We shall therefore have to change the classical theory and introduce into it those physical factors which are the reason for the lesser action of the real pump. These factors are as follows:

2 *Real Angle of Water Leaving Blades at Exit.* Centrifugal-pump designers have long known that in the actual pump the water does not leave the blades tangentially, as assumed in the one-dimensional theory, but at an angle always smaller than that of the blades. The author will not discuss here the probable reasons for this fact. Possibly the principle of least resistance plays a certain role here. But whatever reasons may be involved we must take this fact into consideration. It is one of the material reasons for the deviation between theory and practice, and a knowledge of the water angle for every given blade angle is of great importance for the centrifugal-pump designer. By means of the method about to be described, this leaving angle of the water may be determined from ordinary pump performance curves.

3 *Whirl Component at Exit.* This is a physical factor taking into consideration the definite number of blades in the real pump rather than the infinite number of blades assumed in the classical theory. It has been introduced by various authors, especially in the hydrodynamic studies of Kucharski in his Movements of a Frictionless Fluid, Munich and Berlin, 1918, and Movements in the Rotating Channel, in *Zeitschrift fur das Gesamte Turbinenwesen*, 1917, The Steam Turbine, by Stodola, fifth edition, and The Centrifugal Pump, by Pfleiderer, Berlin, 1924, in which the idea has found a special application to centrifugal pumps. To explain the idea briefly, a centrifugal pump with a small number of blades can only transfer energy to the water if there is a difference of pressure between the acting and non-acting sides of the blades. This is only possible if the velocities on the acting side of the blade are smaller than on the opposite side. For the main flow of water through the impeller this is not possible if the blade thickness is assumed to be negligible. It is therefore necessary to combine with this main flow another flow of water rotating within the blades and in a direction opposite to the rotation of the impeller (see Fig. 1). This is the whirl flow. On the acting side of the blades this whirl flows counter to the main flow, thus reducing the resultant velocity, while on the non-acting side the opposite is the case.

At the periphery of the impeller the direction of the whirl is opposite to the rotation and therefore its velocity is opposite to the component of the absolute velocity in the tangential direction. This component of the absolute velocity is therefore reduced by the whirl component, as is also in consequence the moment given to the water by the blades. It is this whirl component which will have to be deduced from tests. The influence of this whirl component is not as great as it seems to appear in the studies of the above-mentioned authors, for the

[1] Bethlehem Shipbuilding Corporation. Mem. A.S.M.E.

Contributed by the Hydraulic Division and presented at the Annual Meeting, New York, December 5 to 8, 1927, of The American Society of Mechanical Engineers. First presented at a meeting of the Metropolitan Section, New York, March 9, 1927.

reason that these authors do not take in consideration the difference between the leaving angle of the water and the blade angle. They therefore introduce into this correction factor the influence of both, which makes the whirl component appear larger than it is.

4 *Rotation Component at Entrance.* The classical theory does not neglect this factor, but practice generally does in assuming a "normal" entrance, the absolute entrance velocity

FIG. 1

being taken normal to the circumferential velocity, in order to simplify the equations. But as an existing rotation component at the entrance would diminish the total created head, we cannot neglect it. Such a rotation of the water probably exists already in the suction pipe of the pump and the contact of the water with the rotating parts, pump shaft, and hub of the impeller will tend to increase this component. At least we shall introduce this rotation component in our equations, and the analysis of given tests will show if such a rotation exists and to what extent.

5 *Case Factor.* The factors mentioned in 1, 2, 3, and 4 are correction factors for the impeller alone. But the impeller alone does not determine a pump for given conditions of capacity and head at the point of highest efficiency. It is the case or the volute which determines this and it will be shown later how mathematically the volute and impeller are connected together for given conditions of capacity and head. For certain conditions the case is not arbitrary but theoretically determined, and it is necessary to introduce a case factor to bring in accordance the theoretical calculation of the case with actual experience. The definition of this case factor will be given later in the paper.

The knowledge of factors 1 to 5 for a series of pumps will enable the pump designer to calculate a pump for any condition with a high degree of accuracy and to answer any questions which may arise in the pump practice, such as changing the impeller in a given pump, changing the volute for a given impeller, or turning down the blades of a given pump.

It is now in order to develop the equations on which the analysis will be based. The following abbreviations will be used.

$H$ = total head created by impeller
$h$ = actual head measured.
$u_1$ = peripheral velocity at entrance of impeller
$u_2$ = peripheral velocity at exit
$C_1$ = absolute velocity at entrance
$C_2$ = absolute velocity at exit
$C_{u1}$ = projection of absolute velocity on $u_1$
$C_{u2}$ = projection of absolute velocity on $u_2$
$C_{r1}$ = radial component of absolute velocity at entrance
$C_{r2}$ = radial component of absolute velocity at exit
$\alpha$ = angle between absolute velocity and $u$
$\beta$ = angle between relative velocity and $u$
$\gamma$ = specific gravity of the liquid
$g$ = acceleration of gravity.

### THE EQUATION OF THE TOTAL HEAD

The equation of the total head in the classical one-dimensional theory is

$$H = \frac{1}{g}(u_2C_{u2} - u_1C_{u1}) \dots\dots\dots\dots\dots [1]$$

Figs. 2 and 3 show the exit and entrance diagrams representing Equation [1]. Generally it is assumed that $\alpha_1$ = 90 deg. or $C_{u1} = 0$, whence, from Fig. 2,

$$\frac{C_{r2}}{u_2 - C_{u2}} = \tan \beta_2$$

or

$$C_{u2} = u_2\left(1 - \frac{C_{r2}}{u_2 \tan \beta_2}\right)$$

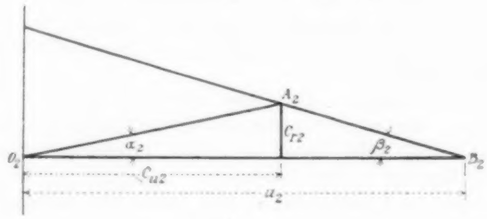


FIG. 2

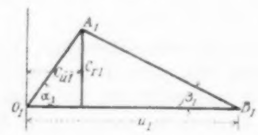


FIG. 3

and

$$H = \frac{u_2^2}{g}\left(1 - \frac{C_{r2}}{u_2 \tan \beta_2}\right) \dots\dots\dots\dots [1']$$

$C_{r2}$ represents the capacity, as the capacity only differs from $C_{r2}$ by a constant—the exit section of the impeller. Assuming that for various capacities or various diagrams $\beta_2$ remains constant, it follows from Equation [1] that the total-head capacity characteristic is a straight line.

### ASSUMPTION

*The only assumption made in this connection is that in an actual pump the total-head-capacity characteristic is also a straight line.* This assumption is well based on experience and on tests of various types of centrifugal pumps. Taking now into consideration $C_{u1}$ and introducing in the exit diagram the whirl component $u_w$, Fig. 4 results. Here $O_2B_2C_2$ is the theoretical triangle for an infinite number of blades. $A_2C_2 = u_w$ is the whirl component, and $O_2A_2B_2$ the real triangle. The whirl deviates the relative velocity opposite to the rotation, and decreases the component of the absolute velocity by $u_w$. $A_2C_2$ is parallel to $u_2$ because the capacity and therefore $C_{r2}$ is not changed by the whirl component. Fig. 5, $O_1A_1B_1$, is the entrance diagram and the initial equation for the total head is again

$$H = \frac{1}{g}(u_2C_{u2} - u_1C_{u1}) \dots\dots\dots\dots\dots [1]$$

where $C_{w2}$ represents the component of the absolute velocity of the *real* pump, and the component is smaller compared to the theoretical one by $u_w$.

According to the assumption made above, Equation [1] for various capacities must be a linear function. This will be the case if the points $A_1$ and $A_2$ of the diagrams, by varying $C_r$ will describe themselves straight lines, because then $C_{r1}$ will be a linear function of $C_{u1}$, and $C_{r2}$ a linear function of $C_{u2}$ and the connection of both by Equation [1], a linear function itself, will remain linear. This condition of $A_1$ and $A_2$ describing straight lines is surely sufficient as it would be highly

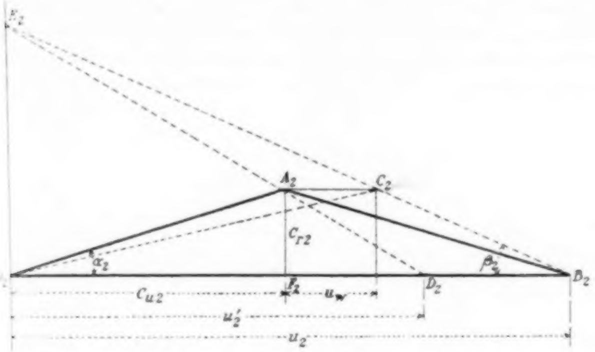



Fig. 4

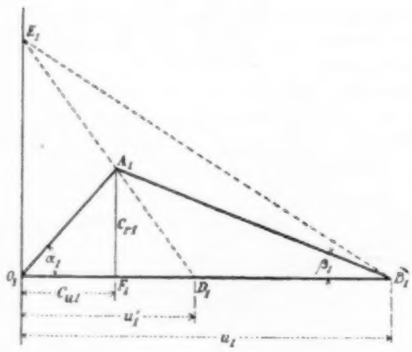



Fig. 5

improbable that $A_1$ and $A_2$ would describe curves symmetrical to a straight line so that their sum would be a liner function.

Another consideration which fixes the straight lines described by $A_1$ and $A_2$ is the point of the characteristic where the total head is zero. For this case we have a purely radial flow through the impeller without transfer of energy from the blades to the water. The whirl at the exit must, therefore, be zero as also are $C_{u1}$ and $C_{u2}$. It follows that for this point of $H = 0$, the exit diagram (see Fig. 4) must be $O_2E_2B_2$, and therefore, the straight line described by $A_2$ must intersect the axis of ordinates in $E_2$. The entrance diagram for this point is $O_1B_1E_1$ and the straight line described by $A_1$ must intersect the axis in $E_1$.

It is now possible in our system of coordinates (see Figs. 4 and 5) to develop the equations for the straight lines described by $A_1$ and $A_2$.

In the exit diagram, Fig. 4, the straight line of $A_2$ starting from $E_2$ intersects the $u_2$ axis in $D_2$. Call $O_2D_2 = u_2'$ and use this value as the unknown representing the whirl, for, knowing $u_2'$, we know the whirl component $u_w$ in every diagram. From the similar triangles $A_2F_2D_2$ and $O_2D_2E_2$, it is seen that

$$\frac{O_2E_2}{C_{r2}} = \frac{u_2'}{u_2' - C_{u2}}$$

$$O_2E_2 = u_2 \tan \beta_2$$

therefore,

$$C_{u2} = u_2' \left(1 - \frac{C_{r2}}{u_2 \tan \beta_2}\right) \qquad [2]$$

In the entrance diagram, Fig. 5, the radial velocities $C_{r1}$ and $C_{r2}$ are connected together by the equation of continuity

$$C_{r1}F_1 = C_{r2}F_2$$

where

$F_1$ = section at entrance of impeller
$F_2$ = section at exit of impeller.

For the point $H = 0$ the radial velocity at the exit is

$$C_{r2(\text{ex.})} = O_2E_2 = u_2 \tan \beta_2$$

and at the entrance

$$C_{r1(\text{ent.})} = O_1E_1 = u_2 \tan \beta_2 \frac{F_2}{F_1}$$

The straight line followed by $A_1$ intersects the $u_1$ axis in $D_1$ and $O_1D_1 = u_1'$ will be taken as the unknown characterizing the entrance rotation, for, knowing $u_1$, $C_{u1}$ is known for every diagram.

It follows from the similar triangles $A_1F_1D_1$ and $O_1E_1D_1$ that

$$\frac{C_{r1}}{O_1E_1} = \frac{u_1' - C_{u1}'}{u_1'}$$

$$\frac{C_{r2}\left(\dfrac{F_2}{F_1}\right)}{u_2 \tan \beta_2 \left(\dfrac{F_2}{F_1}\right)} = \frac{u_1' - C_{u1}}{u_1'}$$

or

$$C_{u1} = u_1' \left(1 - \frac{C_{r2}}{u_2 \tan \beta_2}\right) \qquad [3]$$

Substituting these values in Equation [1] equation of the total head reads;

$$H = \frac{(u_2u_2' - u_1u_1')}{g} \left(1 - \frac{Cr_2}{u_2 \tan \beta_2}\right) \qquad [4]$$

$$\text{For } C_{r2} = 0, \quad H = \frac{u_2u_2' - u_1'u_1}{g}$$

$$\text{For } H = 0, \quad C_{r2} = u_2 \tan \beta_2$$

In analyzing a test, $u_2'$, $u_1'$, and $\tan \beta_2$ are to be considered as unknown and have to be determined by other conditions which it is the author's purpose to develop.

### The Hydraulic Efficiency

The hydraulic efficiency is the ratio between the measured head $h$ and total head $H$.

$$\eta_h = \frac{h}{H}$$

In a given test $h$ is a given function of $C_r$ and $H$ is determined by Equation [4]. The hydraulic efficiency is therefore a function of $C_r$ also, and is a maximum when

$$\frac{d\eta_h}{dC_r} = 0$$

$$\frac{d\eta_h}{dC_r} = \frac{H\dfrac{dh}{dC_r} - h\dfrac{dH}{dC_r}}{H^2}$$

and it follows for the maximum condition that

$$H \frac{dh}{dC_r} - h \frac{dH}{dC_r} = 0$$

$$\frac{1}{H} \cdot \frac{dH}{dC_r} = \frac{1}{h} \cdot \frac{dh}{dC_r}$$

$dH/dC_r$ is the tangent of the angle which the total-head straight line forms with the positive $C_r$ axis, Fig. 7, while $dh/dC_r$ is the tangent of the angle which the tangent to the characteristic curve at the point of maximum hydraulic efficiency forms with the positive $C_r$ axis (Fig. 7). Therefore

$$\frac{dH}{dC_r} = -\tan\gamma' = -\frac{H}{AP}$$

$$\frac{dh}{dC_r} = -\tan\gamma = -\frac{h}{AP}$$

and

$$\frac{H}{H \cdot AP} = \frac{h}{h \cdot AP}$$

or

$$AP = AP$$

It is thus seen that *the tangent to the characteristic curve at the point of maximum hydraulic efficiency intersects the $C_r$ axis at the same point as the total-head straight line*, which point is $C_{r0} = u_2 \tan\beta_2$.

If by some other condition we determine the point $P$ we can project from $P$ the tangent to the characteristic curve and thus find the point of maximum hydraulic efficiency. In order to find this other condition, we shall have to use another curve obtainable from tests, namely, the brake-horsepower curve. Therefore, for the purpose of comparison, it will be necessary to develop the equation of the total hydraulic energy received by the water from the blades.

### The Total Hydraulic Energy

If in Equation [4] we multiply the total head by the capacity, we obtain the equation for the total hydraulic energy. It is desirable to express this energy in horsepower as it will have to be compared with the brake-horsepower curve. Calling the total energy $E_t$, then

$$E_t = c\gamma QH$$

where $c$ = constant for expressing the energy in hp.
$\gamma$ = specific gravity of liquid, and
$Q$ = capacity per unit of time.

Taking $Q = F_2 \times C_{r2}$ and inserting the value of $H$ from Equation [4] in the above expression will give

$$E_t = c \cdot \gamma F_2 \left(\frac{u_2u_2' - u_1u_1'}{g}\right)\left(C_r - \frac{C_r^2}{u_2 \tan\beta_2}\right) \quad \ldots [5]$$

Equation [5] is a parabola; $E_t = 0$ where $C_r = 0$ and also where $C_r = u_2 \tan\beta_2$. This parabola intersects the $C_r$ axis at the same point as the total-head straight line.

The total-energy curve has its maximum when

$$\frac{dE_t}{dC_r} = 0$$

$$\frac{dE_t}{dC_r} = c\gamma F_2 \left(\frac{u_2u_2' - u_1u_1'}{g}\right)\left(1 - \frac{2C_r}{u_2 \tan\beta_2}\right)$$

It therefore follows that the maximum is reached when

$$C_r = \frac{u_2 \tan\beta_2}{2} \quad \ldots\ldots\ldots\ldots [6]$$

The maximum of the total-energy curve is reached at a capacity which is half the capacity at which the total created head is zero. This fact is important and will be made use of later.

### Comparison Between Brake-Horsepower Curve and Total-Hydraulic-Energy Curve

The brake horsepower is the energy input into the pump. It has to cover the total hydraulic energy created and the friction losses of a mechanical nature such as the disk friction and the friction in the stuffing boxes and bearings, leakage for the moment being neglected. The leakage in a centrifugal pump is usually


Fig. 6

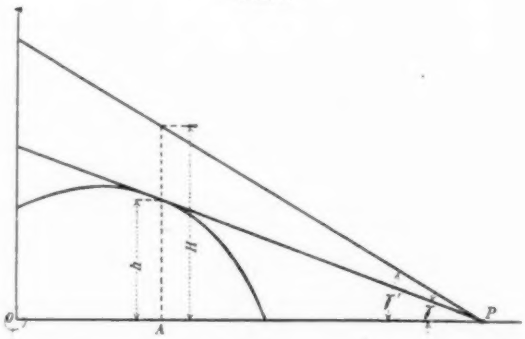


Fig. 7

very small. In the first attempt at analyzing a test curve the leakage cannot be considered as we do not yet know the diagrams of the pump and so are not able to calculate the static pressure at the exit of the impeller, which determines the leakage. We must, therefore determine our diagrams first without considering leakage. With these diagrams we can determine the leakage and in a second attempt can analyze our test curves, taking the leakage into consideration, as will be shown later.

Letting $E_B$ = brake-horsepower input into the pump
$E_t$ = total hydraulic energy, and
$E_R$ = sum of mechanical exterior friction losses,

follows from the above statement that

$$E_B = E_t + E_R \quad \ldots\ldots\ldots\ldots [7]$$

in which $E_B$ is a function of $C_r$, given by test; $E_t$ is a function of $C_r$, given by Equation [5]; and $E_R$ is constant and independent of $C_r$.

The exterior mechanical friction losses are dependent only upon the speed, which in the tests is kept constant. The friction

on the side walls of the impeller, in the bearings and stuffing boxes can surely have no relation whatever to the capacity of the pump.

If we now differentiate Equation [7] we obtain

$$\frac{dE_B}{dC_r} = \frac{dE_t}{dC_r} \qquad [8]$$

and we conclude from Equation [8] that

*For any point of capacity the tangent to the brake-horsepower curve and the tangent to the total-hydraulic-energy parabola are parallel.*

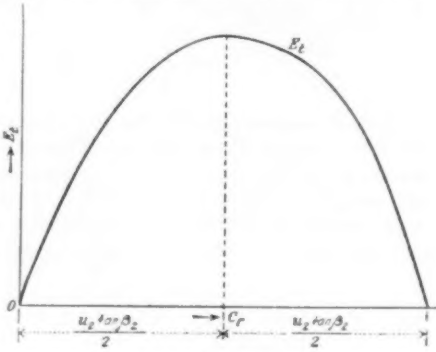


FIG. 8

Equation [8] holds only valuable for a limited range around the points of maximum hydraulic and total efficiencies. Where the capacities are small it is known that besides the main flow there is a secondary flow of the water which acquires energy that is not independent of the capacity. Therefore another element enters into Equation [7] that is dependent on the capacity and so Equation [8] loses its value. It is interesting to note that when we come to determine the parabola of the total hydraulic energy we shall be able at the same time to determine this range of secondary water movements in the impeller.

## THE TOTAL EFFICIENCY

The total efficiency is a known value, obtained by tests as a function of the capacity. But its maximum is sometimes difficult to determine exactly as the efficiency curve is often very flat at the maximum. It is, therefore, desirable to obtain a method by means of which this point of maximum efficiency can be determined with greater precision.

By definition, the total efficiency is

$$\eta_t = \frac{c\gamma Qh}{E_B}$$

$c\gamma Qh$ is the so-called water horsepower or the amount of energy in hp. which the water effectively possesses when leaving the pump.

Calling the water horsepower $E_W$, then

$$\eta_t = \frac{E_W}{E_B}$$

$E_W$ is a given function of the capacity. We can obtain this function graphically by multiplying at every point the capacity by the head of the characteristic curve at that point and by a constant to express the result in horsepower. $E_B$ is a given function of the capacity-b.hp. curve.

The maximum of $\eta_t$ is reached when $\frac{d\eta_t}{dC_r} = 0$

$$\frac{d\eta_t}{dC_r} = \frac{E_B \cdot \frac{dE_W}{dC_r} - E_W \frac{dE_B}{dC_r}}{E_B^2} = 0$$

It follows, therefore, that

$$\frac{1}{E_B} \times \frac{dE_B}{dC_r} = \frac{1}{E_W} \times \frac{dE_W}{dC_r}$$

Similarly as in the case of the hydraulic efficiency, the above equation states that:

*At the point of maximum total efficiency the tangent to the b.hp. curve and the tangent to the water-hp. curve intersect in a point lying on the $C_r$ axis.*

Knowledge of this fact will make it possible, in case of necessity, to determine more exactly the point of best total efficiency. See Fig. 9.

## GRAPHICAL DETERMINATION OF THE TOTAL-HYDRAULIC-ENERGY PARABOLA

Sufficient conditions have now been developed to make it possible to determine from the given test curves the parabola of the total hydraulic energy and in consequence the total-head straight line. The author will divide this problem into two parts.

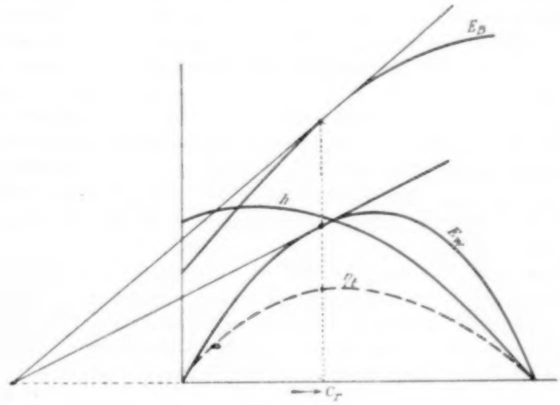


FIG. 9

(*a*) *The Brake-Horsepower Curve Has a Maximum.* In this case and in consequence of Equation [8] it is known that the parabola of the total hydraulic energy has its maximum at the same capacity as the b.hp. curve and intersects the axis at twice this capacity.

Calling the radial velocity at the point of the b.hp. maximum $C_{rm}$, then Equation [6] gives

$$C_{rm} = \frac{u_2 \tan \beta_2}{2}$$

$$\tan \beta_2 = \frac{2 \cdot C_{rm}}{u_2} \qquad [9]$$

*Equation [9] makes it possible to determine the real angle with which the water leaves the blades.*

Knowledge of the location of point $P$ allows now the drawing of a tangent to the given characteristic curve, and *the point where this tangent touches the curve is the point of maximum hydraulic efficiency.*

From the parabola of total hydraulic energy we know now the chord $OP$ and the $C_r$ at which the maximum is attained.

The parabola is completely determined if we add another condition due to Equation [8] when we choose the direction of

the tangent at another value of $C_r$ of the parabola. For this we may choose the tangent $m$-$m$ on the b.hp. curve at the point of highest total or hydraulic efficiency, to which the corresponding tangent of the parabola at the same value of $C_r$ is parallel. From the analytical geometry of the parabola we now recall the following statements (see Figs. 10 and 11).

1 A diameter $EQ$ of the parabola bisects all chords $OA$ which are parallel to the tangent $m'$-$m'$ at its end point $E$ so that $OB = BA$ (see Fig. 10). This statement allows us to obtain the point $A$ of our parabola if we draw $OA$ parallel to the tangent chosen on the b.hp. curve and make $OB = BA$.

2 To obtain other points of the parabola the construction given in Fig. 11 may be employed. Given a chord $OP$ of the parabola normal to the axis and a point $A$. Erect $PR$ and $AQ$ perpendicular to $OP$ and draw $OAR$ and $QR$. If we draw $A_1Q_1$ perpendicular to $OP$ and $Q_1R_1$ parallel to $QR$, then the line $OR_1$ will intersect the line $Q_1A_1$ in the point $A_1$ of the parabola.

From the parabola the total-head straight line may be found by dividing at any point of $E_t$ by a constant and $C_r$ as shown previously. The ratios between the characteristic curve and the total head $H$ gives the curve of hydraulic efficiencies and its maximum at the previously determined point. The difference between $E_B$ and $E_t$ at any point, for example, at the maximum total efficiency, gives the external friction losses. If we add to the total energy of the parabola this amount of friction losses, we obtain a curve which is the b.hp. curve at the maximum efficiencies. This curve deviates from the b.hp. curve obtained by test at the origin of the characteristic and the differences between the two curves gives the energy of the secondary movements in the impeller. The intersection of the straight line of the total head with the axis of ordinates gives us the value $(1/g)(u_2u_2' - u_1u_1')$.

*Analytical Solution.* Instead of constructing the parabola geometrically, we can of course calculate it analytically. Calling $C_{rm}$ the radial velocity at the point where the b.hp. curve has a maximum and $C_{rt}$ the radial velocity at the point of highest total efficiency, then Equation [5] below gives the parabola.

$$E_t = c\gamma F_2\left(\frac{u_2u_2' - u_1u_1'}{g}\right)\left(C_r - \frac{C_r^2}{u_2 \tan \beta_2}\right)$$

and

$$\frac{dE_t}{dC_r} = c\gamma F_2\left(\frac{u_2u_2' - u_1u_1'}{g}\right)\left(1 - \frac{2C_r}{u_2 \tan \beta}\right)$$

for $$C_r = C_{rm}, \quad \frac{dE_t}{dC_r} = 0, \quad \text{hence } \tan \beta_2 = \frac{2\,C_{rm}}{u_2}$$

for $$C_r = C_{rt}, \quad \frac{dE_t}{dC_r} = \tau$$

where $\tau$ is the slope of the b.hp. curve at the point of best efficiency

$$\tau = c\gamma F_2\left(\frac{u_2u_2' - u_1u_1'}{g}\right)\left(1 - \frac{2\,C_{rt}}{u_2 \cdot \dfrac{2C_{rm}}{u_2}}\right)$$

therefore

$$(u_2u_2' - u_1u_1') = \frac{g \cdot \tau}{c\gamma F_2}\,\frac{1}{\left(1 - \dfrac{C_{rt}}{C_{rm}}\right)}$$

and

$$E_t = \frac{\tau}{\left(1 - \dfrac{C_{rt}}{C_{rm}}\right)}\left(C_r - \frac{C_r^2}{C_{rm}}\right) \quad [10]$$

Equation [10] gives the parabola of the total hydraulic energy if $C_{rm}$, $C_{rt}$ and $\tau$ are known from the test.

From Equation [10] the equation of the total-head straight line $H$ may be derived:

$$H = \frac{E_t}{c \cdot \gamma F_2 \cdot C_r} = \frac{\tau}{c\gamma F_2\left(1 - \dfrac{C_{rt}}{C_{rm}}\right)}\left(1 - \frac{C_r}{2\,C_{rm}}\right) \quad [11]$$

also, for $C_r = 0$,

$$\frac{u_2u_2' - u_1u_1'}{g} = \frac{\tau}{c\gamma F_2\left(1 - \dfrac{C_{rt}}{C_{rm}}\right)} \quad [12]$$

(*b*) *The Brake-Horsepower Curve Has No Maximum.* In principle this case does not differ from the previous one. We used the knowledge of the direction of two tangents to the parabola and instead of employing the horizontal tangent as before we must employ in addition to the tangent at the point of maximum total efficiency, another tangent, as for example,

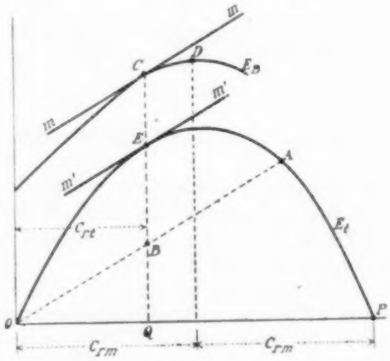


FIG. 10

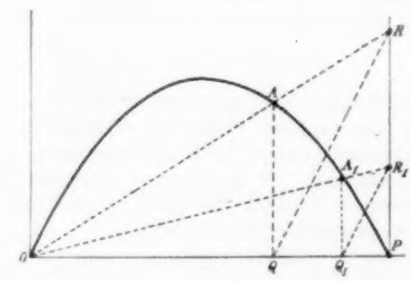


FIG. 11

at the point of maximum hydraulic efficiency. If these points are too close together, any other point on the b.hp. curve where the secondary movements have not influenced it as yet, may be used.

*Graphical Solution.* Knowledge of the directions of two tangents on the parabola makes it possible to determine two points of the parabola $A_1A_2$ as previously described. In order to find the intersection of the parabola with $C_r$ axis, use the construction indicated in Fig. 12. Make $Q_2B_2 = Q_1B_1$ and connect $A_1$ with $B_2$. The line $A_1B_2$ intersects the $C_r$ axis at the characteristic point $P$. Thus this problem is brought back to the graphical solution of the previous one.

*Analytical Solution.* Calling the radial velocities at the two points where the tangents are known $C_{rt}$ and $C_{rh}$ and $\tau_t$ and $\tau_h$ the tangents of the angles which these tangents respectively form with the positive $C_r$ axis, then the following conditions obtain:

For $C_r = C_{rt}$, $\dfrac{dE_t}{dC_r} = \tau_t$

for $C_r = C_{rh}$, $\dfrac{dE_t}{dC_r} = \tau_h$

$$\tau_t = c\gamma F_2 \left(\frac{u_2u_2' - u_1u_1'}{g}\right)\left(1 - \frac{2\,C_{rt}}{u_2 \tan \beta_2}\right)$$

$$\tau_h = c\gamma F_2 \left(\frac{u_2u_2' - u_1u_1'}{g}\right)\left(1 - \frac{2\,C_{rh}}{u_2 \tan \beta_2}\right)$$

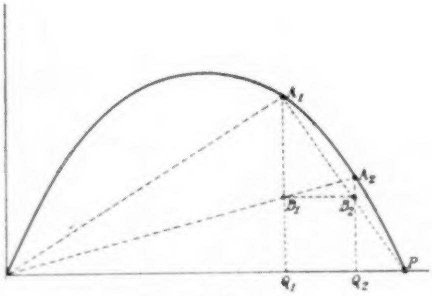

FIG. 12

$$\frac{\tau_t}{\tau_h} = \frac{1 - \dfrac{2\,C_{rt}}{u_2 \tan \beta_2}}{1 - \dfrac{2\,C_{rh}}{u_2 \tan \beta_2}}$$

from which

$$\tan \beta_2 = \frac{2\left(C_{rt} - \dfrac{\tau_t}{\tau_h}\,C_{rh}\right)}{\left(1 - \dfrac{\tau_t}{\tau_h}\right)u_2} \qquad [13]$$

Equation [13] gives the leaving angle of the water.

$$c\gamma F_2\left(\frac{u_2u_2' - u_1u_1'}{g}\right) = \frac{\tau_t}{1 - \dfrac{2\,C_{rt}}{u_2 \tan \beta_2}}$$

and $\tan \beta_2$ of Equation [13] gives

$$c\gamma F_2\left(\frac{u_2u_2' - u_1u_1'}{g}\right) = \frac{\tau_t}{1 - \dfrac{C_{rt}\left(1 - \dfrac{\tau_t}{\tau_h}\right)}{C_{rt} - \dfrac{\tau_t}{\tau_h}\,C_{rh}}}$$

$$E_t = \frac{\tau_t}{1 - \dfrac{C_{rt}\left(1 - \dfrac{\tau_t}{\tau_h}\right)}{C_{rt} - \dfrac{\tau_t}{\tau_h}\cdot C_{rh}}}\left[C_r - \frac{C_r^2\left(1 - \dfrac{\tau_t}{\tau_h}\right)}{2\left(C_{rt} - \dfrac{\tau_t}{\tau_h}\,C_{rh}\right)}\right] \qquad [14]$$

and the total-head straight line is given by:

$$H = \frac{E_t}{c\gamma F_2 C_r} = \frac{\tau_t}{c\gamma F_2}\left[\frac{1}{1 - \dfrac{C_{rt}\left(1 - \dfrac{\tau_t}{\tau_h}\right)}{C_{rt} - \dfrac{\tau_t}{\tau_h}\,C_{rh}}}\right]$$

$$\times \left[1 - \frac{C_r\left(1 - \dfrac{\tau_t}{\tau_h}\right)}{2\left(C_{rt} - \dfrac{\tau_t}{\tau_h}\,C_{rh}\right)}\right] \qquad [15]$$

Also

$$\frac{u_2u_2' - u_1u_1'}{g} = \frac{\tau_t}{c\;\gamma F_2}\left[\frac{1}{1 - \dfrac{C_{rt}\left(1 - \dfrac{\tau_t}{\tau_h}\right)}{C_{rt} - \dfrac{\tau_t}{\tau_h}\cdot C_{rh}}}\right] \qquad [16]$$

### DETERMINATIONS OF THE VALUES OF $u_1'$ AND $u_2'$

From the analysis so far developed we can obtain the value of the expression $u_2u_2' - u_1u_1'$, but as yet no method of separately determining $u_1'$ and $u_2'$ has been given. For this another condition is required and therefore the following assumption, which is well founded both theoretically and practically, will be made.

*Assumption.* At the point of maximum total efficiency the water enters the blades without shock; in other words, the water enters the blades tangentially at the angle $\beta_1$ which is known from the design of the pump. This determines $u_1'$ completely.

In laying out the entrance diagram (Fig. 13), $\beta_1$ is known and the radial velocity at the entrance for the point of maximum total efficiency is $C_{r1t}$, thus determining the triangle $OA_1B_1$ and $C_{u1}$. From the analysis $OE_1$ is known:

$$OE_1 = u_2 \tan \beta_2 \cdot \frac{F_2}{F_1}$$

Connecting $E_1$ with $A_1$ we obtain $D_1$ and $u_1'$, and from similar triangles we obtain

$$\frac{C_{r1t}}{u_2 \tan \beta_2 \dfrac{F_2}{F_1}} = \frac{u_1' - C_{u1}}{u_1'} = \frac{u_1' - \left(u_1 - \dfrac{C_{r1t}}{\tan \beta_1}\right)}{u_1'}$$

and

$$C_{r1t} = C_{rt}\,\frac{F_2}{F_1}$$

Where $C_{rt}$ is the radial velocity at exit,

$$u_1' = \frac{u_1 - \dfrac{C_{rt}\cdot F_2}{\tan \beta_1 F_1}}{1 - \dfrac{C_{rt}}{u_2 \tan \beta_2}} \qquad [17]$$

Knowing $u_1'$ from our analysis and $\dfrac{u_2u_2' - u_1u_1'}{g}$, the value of $u_2'$ is of course determined, and with it the exit diagram and $C_{u2}$ (see Fig. 14). We know from our analysis $\beta_2$, $u_2'$, and $C_{r2}$, the radial velocity at the point of maximum efficiency, and thus obtain $C_{u2}$ and the real whirl component $u_w$.

From similar triangles

$$\frac{u_w}{u_2 - u_2'} = \frac{u_2 \tan \beta_2 - C_{r2}}{u_2 \tan \beta_2}$$

$$u_w = (u_2 - u_2')\left(1 - \frac{C_{r2}}{u_2 \tan \beta_2}\right) \qquad [18]$$

and $C_{u2}$ is given by:

$$C_{u2} = u_2 - \frac{C_{r2}}{\tan \beta_2} - u_w$$

hence

$$C_{u2} = u_2' \left(1 - \frac{C_{r2}}{u_2 \tan \beta_2}\right) \quad \ldots\ldots\ldots\ldots [19]$$

At the beginning of the paper reference was made to The Centrifugal Pump, by C. Pfleiderer (Berlin, 1924, Julius Springer). In this work Herr Pfleiderer develops the following formula for the whirl component $u_x$:

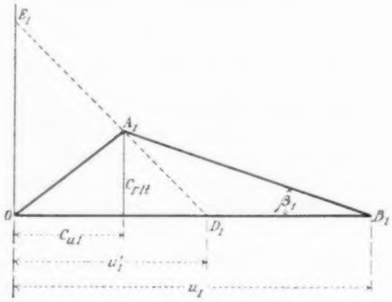

FIG. 13

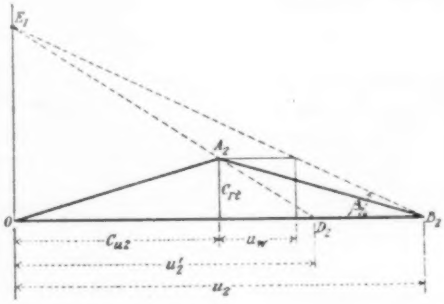

FIG. 14

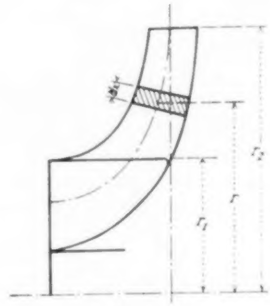

FIG. 15

$$u_w = \psi \frac{g r_2^2 H}{z S u_2}$$

where $\psi$ = a dimensionless constant
$z$ = number of blades
$r_2$ = impeller radius at exit, and
$S$ = static moment of average streamline in the impeller.

$$S = \int_{r_1}^{r_2} r dx \text{ (see Fig. 15)}$$

for $C_r = 0$, $H = \frac{u_2 u_2' - u_1 u_1'}{g}$ and $u_w = u_2 - u_2'$,

therefore

$$\psi = \left(\frac{zS}{r_2^2}\right)\left[\frac{u_2(u_2 - u_2')}{u_2 u_2' - u_1 u_1'}\right] \quad \ldots\ldots\ldots\ldots [20]$$

Equation [20] will enable us to deduce from our tests the value of $\psi$. Incidentally, it would be highly interesting to determine from a series of tests whether $\psi$ is a real constant independent of the design of the pump.

The analysis of the impeller being completed we are now able to take in consideration the leakage by calculating it from diagrams developed after known methods.[2] But, before proceeding we shall analyze a pump by the methods that have been developed.

## Graphical Analysis of a 10-In. Bethlehem Centrifugal Pump Tested at 1150 R.P.M.

Referring to Fig. 16, the characteristic curve $h$, the b.hp. curve $E_B$, and the total efficiency curve $\eta_t$ are obtained by test. The pump has the following dimensions:

| | |
|---|---|
| Exit diameter | $D_2 = 16^1/_2$ in. |
| Entrance diameter | $D_1 = 8^1/_2$ in. |
| Exit section | $F_2 = 0.509$ sq. ft. |
| Entrance section | $F_1 = 0.466$ sq. ft. |
| Exit angle of the blades | $\beta_2' = 20$ deg. |
| Entrance angle of the blades | $\beta_1 = 15$ deg.; $\tan \beta_1 = 0.2679$ |

[2] It is known from the theory of centrifugal pumps that the leakage varies with the capacity as a flat ellipse. We could calculate this ellipse and from that design the new characteristic curve, and repeat the whole analysis. However, the author will not go into the details of this correction as it would reveal nothing new.

$$u_2 = \frac{\pi \times 1.373 \times 1150}{60} = 82.7 \text{ ft. per sec.}$$

$$u_1 = \frac{8.5 \times 82.7}{16.5} = 42.55 \text{ ft. per sec.}$$

The b.hp. curve has a maximum at a capacity of 2500 gal. per min. = 5.54 cu. ft. per sec. The corresponding radial velocity at the exit is:

$$C_{rm} = \frac{5.54}{0.509} = 10.89 \text{ ft. per sec.}$$

From Equation [9] we therefore obtain the leaving angle of the water at exit.

$$\tan \beta_2 = \frac{2 \times 10.89}{82.7} = 0.263$$

This angle is approximately 14 deg. 45 min. as compared with the 20 deg. of the blades. The maximum hydraulic efficiency occurs at the capacity where a line from the characteristic point $P$ is tangent to the characteristic curve $h$. This capacity is 1940 gal. per min., whereas the maximum total efficiency occurs at the capacity 2000 gal. per min. With the line $m$-$m$ tangent to the b.hp. curve at the point of maximum total efficiency the parabola $E_i$ has been constructed according to the method previously described. The difference between this parabola and the b.hp. curve at the point of maximum total efficiency is 9 hp., which is the value of external friction losses. The horizontally shaded field between the parabola and the b.hp. curve indicates the range of secondary movements and the hp. needed at every capacity for these movements. The total-head straight line $H$ is obtained if one point is deduced from the parabola, as, for example, the point of maximum hydraulic efficiency. At this point $E_i$ = 51 hp., and therefore $H$ = $3960 \times 51/1940 = 104$ ft.

The head $h$ at this point = 94.5 ft., so that the maximum hydraulic efficiency is $\eta_h = 94.5/104 = 0.907$. The straight line intersects the axis of coordinates at a head of 170 ft., so that

$$\frac{u_2 u_2' - u_1 u_1'}{g} = 170 \text{ ft.}$$

The vertically shaded field between the total-head straight line $H$ and the characteristic curve $h$ gives the amount of the hydraulic losses, and the ratio between the two gives the hydraulic-efficiency curve.

The point of maximum total efficiency is at 2000 gal. per min.

= 4.43 cu. ft. per sec. The corresponding radial velocities at entrance and exit are:

$$C_{r2} = \frac{4.43}{0.509} = 8.71 \text{ ft. per sec.}$$

$$C_{r1} = \frac{4.43}{0.466} = 9.5 \text{ ft. per sec.}$$

For the entrance and exit diagrams,

$$OE_2 = u_2 \times \tan \beta_2 = 82.7 \times 0.263 = 21.8 \text{ ft. per sec.}$$

$$u_w = (82.7 - 72.3)\left(1 - \frac{8.71}{82.7 \times 0.263}\right) = 6.25 \text{ ft. per sec.}$$

and from Equation [19]

$$C_{u2} = 72.3\left(1 - \frac{8.71}{82.7 \times 0.263}\right) = 43.4 \text{ ft. per sec.}$$

Using these values, the entrance and exit diagram has been drawn as shown at the left in Fig. 16.

To calculate the constant $\psi$ of Equation [20] we note that the

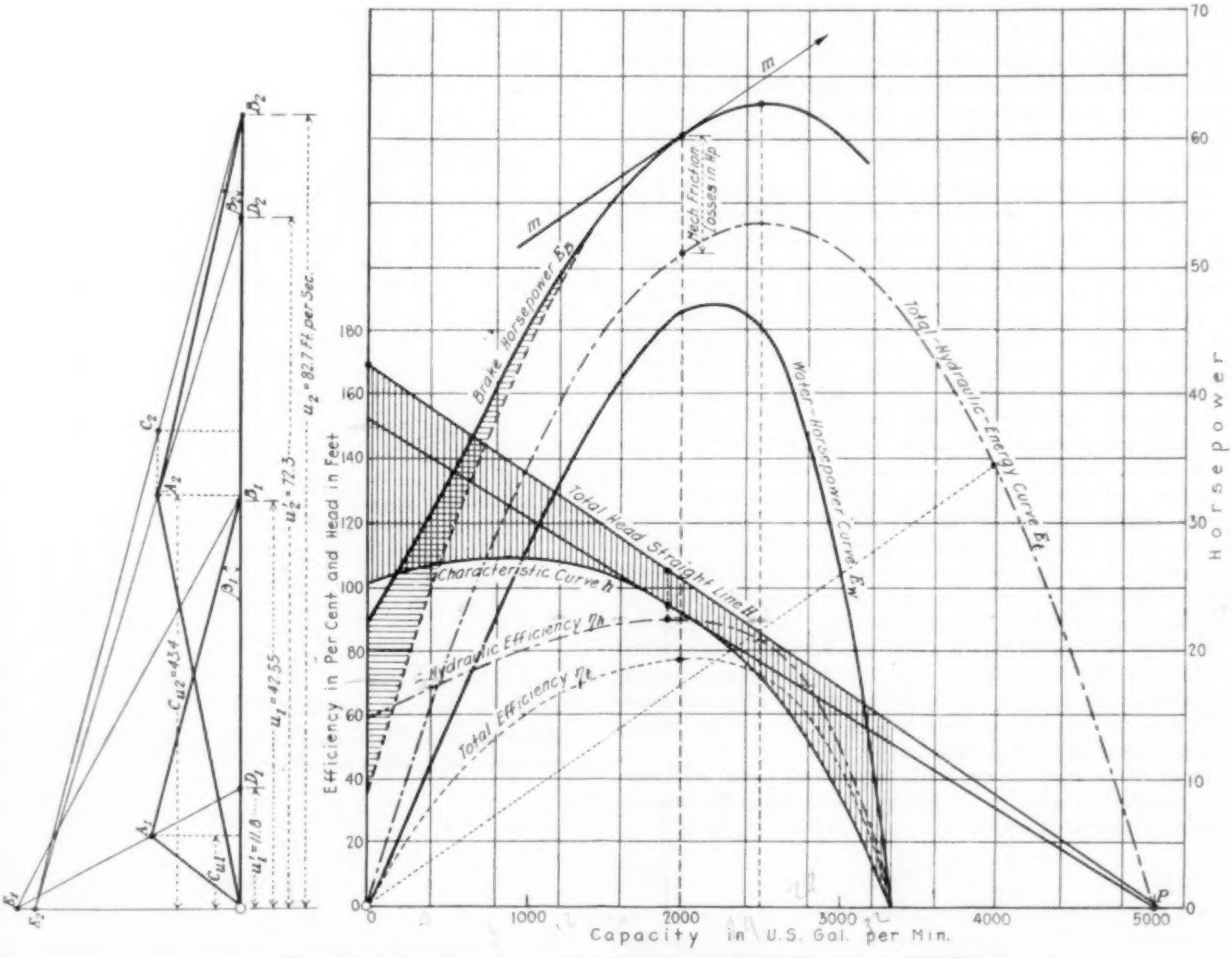


Fig. 16 Graphical Analysis of a 10-In. Centrifugal Pump Tested at 1150 R.P.M.

$$OE_1 = 21.8 \times \frac{0.509}{0.466} = 23.8 \text{ ft. per sec.}$$

and Equation [17] gives the following value of $u_1'$:

$$u_1' = \frac{42.55 - \dfrac{8.71 \times 0.509}{0.2679 \times 0.466}}{1 - \dfrac{8.71}{82.7 \times 0.263}} = 11.8 \text{ ft. per sec.}$$

$$u_2' = \frac{32.2 \times 170 + 11.8 \times 42.55}{82.7} = 72.3 \text{ ft. per sec.}$$

and the real whirl component as given by Equation [18] is

number of blades $z = 9$. The static moment of the average stream line

$$S = \int_{r_1}^{r_2} r dx = 0.17315 \text{ sq. ft.}$$

whence

$$\psi = \left(\frac{9 \times 0.17315}{0.4715}\right)\left[\frac{82.7\,(82.7 - 72.3)}{32.2 \times 170}\right] = 0.52$$

## Connection of Impeller and Casing

Having completed the study of the impeller, it is now necessary to study the second element of the centrifugal pump, the casing, and to develop the equations which connect the case to the impeller.

It has been shown that for a given impeller with given

speed the total-head straight-line characteristic can be completely determined without taking the casing surrounding it into consideration. It has also been shown that the real characteristic curve has its maximum hydraulic efficiency where the tangent drawn from the characteristic point $P$ touches the curve (see Fig. 17). This tangent $P$-$E$ to the characteristic curve is nothing else but the total-head straight line of the impeller for a hydraulic efficiency constant and equal to the maximum hydraulic efficiency of the characteristic curve. The hydraulic efficiency of the real characteristic varies. Any straight line from $P$ represents a total-head characteristic of the impeller for a certain constant hydraulic efficiency ranging from efficiencies of 100 per cent to zero. Such a straight line must intersect the real characteristic curve in the two points where the hydraulic efficiency corresponds to the value of this line. For the maximum hydraulic efficiency the corresponding straight line must be tangent to the characteristic curve, as there is only one point of the real characteristic which has this efficiency.

In enclosing a given impeller in different casings we know from experience that the characteristic curves are different and so are the capacity and head at which the maximum hydraulic efficiency occurs. But the value of this maximum hydraulic efficiency does not change over a wide range of different casings. It follows, therefore, from the considerations stated above that all these different characteristic curves must have the same straight line as a tangent but touching them at various points. This is a fact well proved by actual experience. The casing determines the point of the straight line at which the real characteristic will have its maximum hydraulic efficiency. It is quite evident that for the real pump the casing is of enormous influence and that for a given impeller different cases may create various shapes of characteristics and various points of capacity and head at which the hydraulic efficiency will be maximum. It is therefore necessary to develop the equations which will determine for a given impeller and case the capacity and head at which the hydraulic efficiency will be maximum.

For a given impeller rotating at a certain speed, $u_2$, $u_2'$, and $\beta_2$ of the exit diagram are fixed. The exit diagram for the point of maximum efficiency could be completed if we knew the angle $\alpha_2$ which the absolute velocity makes with $u_2$. The casing, therefore, determines this angle.

From the general theory of the centrifugal pump we know that the flow of water in the casing, after leaving the impeller is governed by the equation:

$$r \times C_u = \text{Constant} \qquad [21]$$

where $r$ is the distance of the particular molecule of water from the axis and $C_u$ the component of its velocity in a tangential direction. Equation [21] is that of a hyperbola which has the axes of ordinates and abscisses as asymptotes. At the exit of the impeller $r = r_2$ the impeller radius, and $C_u = C_{u2}$ as given by the exit diagram, so that

$$rC_u = r_2C_{u2} \qquad [21']$$

If the largest section of the volute is given, Equation [21'] affords a means of calculating at every point of the head $PP'$ (Fig. 19) the corresponding $C_u$ and thus obtaining $AB$ as the curve of velocities. These velocities are theoretical. In reality friction and other reasons reduce these velocities, so that the real velocity curve under which the capacity flows in the case is $AB'$.

Taking now an element $dF$ of the volute area at the radius $r$ and $C_{ut}$ its corresponding theoretical velocity, from the curve $AB$, the corresponding effective velocity $C_{ue}$ is obtained from the curve $AB'$. The real capacity $Q$ flowing through the case is then given by the equation

$$Q = \int_{r_2}^{r_3} dFC_{ue}$$

The same integration with the theoretical velocities

$$\int_{r_2}^{r_3} dFC_{ut}$$

would give a capacity larger than the real capacity.

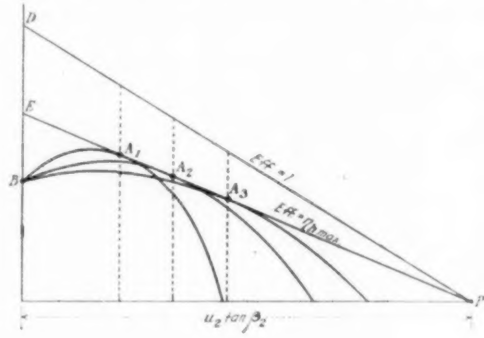


Fig. 17

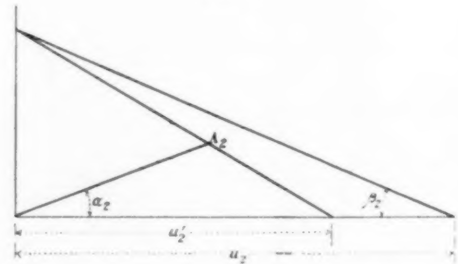


Fig. 18

### The Casing Factor

The ratio of this theoretical capacity to the effective capacity is now taken as a casing factor, or

$$K = \frac{\int_{r_2}^{r_3} dFC_{ut}}{\int_{r_2}^{r_3} dFC_{ue}} \qquad [22]$$

The analysis of the impeller allows us now to deduce from the tests this factor $K$. The capacity at the point of maximum hydraulic efficiency is known and from the exit diagram $C_{u2}$ is obtained, therefore the curve $AB$, determined from the pump dimensions, is the largest volute section. Therefore $\int dFC_{ut}$ can be determined, if not analytically then always graphically and thus the factor $K$ be found. In the example given, the capacity at maximum hydraulic efficiency was 1940 gal. per min. = 4.3 cu. ft. per sec., and $C_{u2}$ was found to be 43.4 ft. per sec. The graphical integration of $\int dFC_{ut}$ gave 6.25 cu. ft. per sec.

Therefore

$$K = \frac{6.25}{4.3} = 1.45$$

When calculating the largest volute section for a new pump we calculate with the theoretical curve $AB$ and with a capacity

K times larger than the real one. Having found this largest section we introduce the effective-velocity curve $AB'$ so that the integration over the known largest volute section gives the effective capacity. We are thus able to determine all the other sections around the volute.

Returning to the problem of connecting impeller and casing, we have to introduce the one element common to both, and this is the flow through impeller and casing at the point of maximum

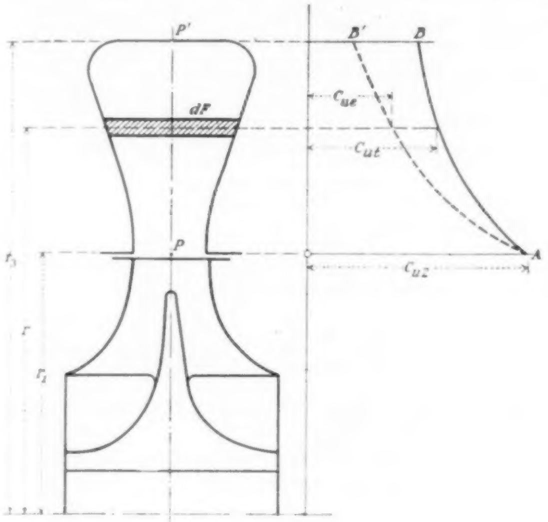


Fig. 19

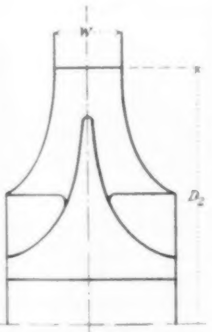


Fig. 20

efficiency. Leakage makes the flow through the impeller somewhat larger than through the casing.

Calling $Q$ now the flow passing the casing, we then have at the exit of the impeller

$$Q + Q_{\text{leak.}} = \phi\pi D_2 W C_{r2}$$

$\phi$ is the ratio between the free exit section and $\pi D_2 W$, $D_2$, and $W$ as shown in Fig. 20. If we put

$$\frac{Q + Q_{\text{leak.}}}{Q} = \epsilon$$

where $\epsilon$ = coefficient of leakage, then

$$Q = \frac{\phi \cdot \pi \cdot D_2 \cdot W \cdot C_{r2}}{\epsilon} \qquad [23]$$

The capacity through the case is given by

$$Q = \frac{1}{K}\int_{r_2}^{r_3} dFC_{ut}$$

From Equation [21′] we deduce that

$$C_{ut} = \frac{r_2}{r} \cdot C_{u2} = \frac{D_2}{2r} C_{u2}$$

and therefore

$$Q = \frac{1}{K}\int_{r_2}^{r_3} dF\,\frac{D_2}{2r} \cdot C_{u2} = \frac{D_2C_{u2}}{2K}\int_{r_2}^{r_3}\frac{dF}{r} \qquad [24]$$

Equations [23] and [24] combined give

$$\frac{\phi\pi D_2 \cdot WC_{r2}}{\epsilon} = \frac{D_2C_{u2}}{2K}\int_{r_2}^{r_3}\frac{dF}{r}$$

and

$$\frac{C_{r2}}{C_{u2}} = \tan\alpha_2 = \frac{\epsilon}{2\pi K\phi W}\int_{r_2}^{r_3}\frac{dF}{r} \qquad [25]$$

Equation [25] connects the impeller and casing. $\int\frac{dF}{r}$ is a purely geometrical value characterizing the largest volute section. It can always be found for every shape of volute by a graphical integration. We now have all the elements of our exit diagram for the point of maximum hydraulic efficiency and therefore know $C_{r2}$ representing the capacity, and $C_{u2}$ representing the total head. In Equation [19] we found that

$$C_{u2} = u_2'\left(1 - \frac{C_{r2}}{u_2\tan\beta_2}\right)$$

If $C_{r2} = C_{u2}\tan\alpha_2$,

$$C_{u2} = u_2'\left(1 - \frac{Cu_2 \cdot \tan\alpha_2}{u_2\tan\beta_2}\right)$$

hence

$$C_{u2} = \frac{u_2'}{1 + \dfrac{u_2'\tan\alpha_2}{u_2\tan\beta_2}} \qquad [26]$$

and

$$C_{r2} = \frac{u_2'\tan\alpha_2}{1 + \dfrac{u_2'\tan\alpha_2}{u_2\tan\beta_2}} \qquad [27]$$

We are now able to obtain the equations for the capacity and total head of a given impeller and given casing.

$$Q = \left(\frac{\phi\pi D_2 \cdot W}{\epsilon}\right)\left[\frac{u_2'\tan\alpha_2}{1 + \dfrac{u_2'\tan\alpha_2}{u_2\tan\beta_2}}\right] \qquad [28]$$

$$H = \left(\frac{u_2u_2' - u_1u_1'}{g}\right)\left[1 - \frac{\dfrac{u_2'}{u_2}\cdot\tan\alpha_2}{\dfrac{u_2'}{u_2}\tan\alpha_2 + \tan\beta_2}\right] \qquad [29]$$

where $\tan\alpha_2$ is determined by Equation [25].

Equations [28] and [29] may be used to calculate a new pump as well as to determine the capacity and head of a pump of given dimensions. They will also be useful in all the many cases of practice where for a given impeller a new case is used or, inversely, a new impeller is made for a given case, and where the exit angle of an impeller is changed or its diameter is reduced. In the latter case, so often applied in centrifugal-pump practice, $u_2$ and $u_2'$ vary in the same proportion as the diameters and Equation [28] shows that the capacities vary as the square of the diameters, whereas Equation [29] indicates that the head is even reduced a little more than would correspond to the square of the diameters.

## Conclusions

The discrepancy between the theoretical results of the classical one-dimensional theory used in calculating centrifugal pumps

and the actual practice, forces us to introduce correction factors which can only be deduced from tests. The designer of centrifugal pumps has at his disposition an abundant amount of ordinary performance curves. This paper has shown a graphical as well as an analytical method of determining from these test curves all the correction factors necessary to bring in accordance theory and practice. At the same time these correction factors have been introduced into the equations of the classical one-dimensional theory, and new equations have thus been developed which can be used for calculating new pumps, on the supposition that these correction factors are known.

It should be noted that the analysis presented is based mainly on the brake-horsepower curve, and its accuracy stands or falls with the accuracy of that curve. Only curves obtained by direct measurement of the b.hp. through torsion or electrical dynamometers should be used, and it is advisable to measure very carefully that portion of the curve around the points of maximum efficiency.

## Discussion

A. F. Sherzer.[3] The early part of the paper[4] states: "But we know that the equation of the total head in the one-dimensional theory indicates a far greater head than the pump actually creates. We shall therefore have to change the classical theory and introduce into it those physical factors which are the reason for the lesser action of the real pump."

He then lists the following factors which bring about this difference:

1 Change in angle of water leaving the blades
2 Whirl component at exit
3 Rotation component at entrance
4 Case factor.

It is not denied that any or all of these may have something to do with the action of the pump, but they are not by any means the sole reason for the lack of agreement between the actual head developed and that called for by the equation for the total head presented in the paper. Concerning the above four factors, which are claimed to represent the reason for the observed lack of agreement, I have little to say, except that the difference between the angle of the water and that of the blade is so slight, if any, that it does little to bring about any agreement.

The whirl component at exit referred to does not seem at all rational, except, possibly, at small rates of flow near shut-off. When operating at the point of best efficiency, it probably does not exist. There is little direct evidence to show that it does, and several carefully made tests to prove that it does not.

The rotation component at entrance is, in my opinion, always present and certainly does increase the head as a result of it. It is hard to see how it could possibly decrease the head, as is claimed by the author. The use of the case factor is very hopeful and, to my mind, entirely correct as a matter of principle. The effect of the case has had scant attention in much of our pump literature.

I would take exception to the statement that Equation [1] of the paper correctly represents the total head developed by a centrifugal pump. This equation

$$H = \frac{1}{g}(u_2C_{u2} - u_1C_{u1})$$

[3] Associate Professor, Department of Mechanical Engineering, University of Michigan, Ann Arbor, Mich.

[4] This discussion is intended by the writer to apply also to the paper, "A New Method of Separating the Losses in a Centrifugal Pump," by M. D. Aisenstein. See paper No. HYD-50-1.

is often claimed to represent either the action of the water turbine or that of the centrifugal pump, provided proper change in notation is used. As it stands, it is no doubt correct for the turbine, but does not hold for the pump. The reason for this is easily seen to be the fact that, in the turbine, the item $u_1C_{u1}$ represents the effect of the angular momentum retained in the water at discharge from the turbine runner, and which may, in cases, oppose the rotation, while in the centrifugal pump all the angular momentum possessed by the water at discharge from the runner has been obtained from it. For this reason, the term $u_1C_{u1}$ does not apply. This is the real reason for dropping the last term, and not, as the author suggests, by reason of the radial entrance of the water which is probably never realized in an actual pump.

With the above change, the equation now becomes:

$$H = \frac{1}{g}u_2C_{u2}$$

and by application of trigonometry, it may be written in the form given by the author in Equation [1] as

$$H = \frac{u_2^2}{g}\left(1 - \frac{C_{r2}}{u_2 \tan \beta_2}\right)$$

The writer prefers a slight modification of the above equation, and would proceed as follows:

$C_{u2} = C_2 \cos \alpha_2$ and $C_2 \cos \alpha_2 = u_2 - w_2 \cos (180° - \beta_2)$ or $C_{u2} = u_2 + w_2 \cos \beta_2$. See Fig. 21.

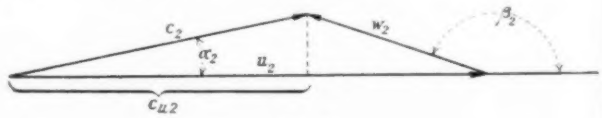


Fig. 21

Now if this value of $C_{u2}$ be substituted in the original equation:

$$H = \frac{1}{g}u_2C_{u2} = \frac{u_2^2}{g} + \frac{u_2w_2}{g}\cos \beta_2 = H \ldots\ldots [30]$$

This is the equivalent of the author's Equation [1'], but is in a form that better illustrates the point the writer desires to make.

The exact physical meaning of the Equation [30] seems to have been completely lost sight of in our present pump literature, and the conditions under which it may be applied are not generally known. That the conditions under which it may be applied are not those found in the centrifugal pump has also been lost sight of, but can be easily proved.

The conditions under which the author's Equation [1'], or the writer's Equation [30], hold are as follows:

1 That each particle of water is introduced at the center
2 That the water is free to accelerate radially in accordance with the motion given to it by the impeller
3 That there are no losses due to the flow through the impeller.

The second of these is the most important. This requires that the water be discharged from the impeller into the atmosphere, and that there be no case to restrain the water from taking on any velocity it may be given by the runner. That is, the present theory is a purely kinetic one and assumes that the total head is represented by the absolute velocity of discharge from the impeller. This is, of course, never realized in an actual centrifugal pump, and hence the theory does not at all agree with the real facts. At first thought, there are probably few who would agree with the above statement. It will therefore be of interest to submit the following proof.

Assume a centrifugal pump, Fig. 22, of a very simple form made by inserting two pipes into a small central pipe supplied with water from a tank. The pipes may be either straight or curved, and we may consider the action of various degrees of curvature. Suppose in the first case the arms be radial.

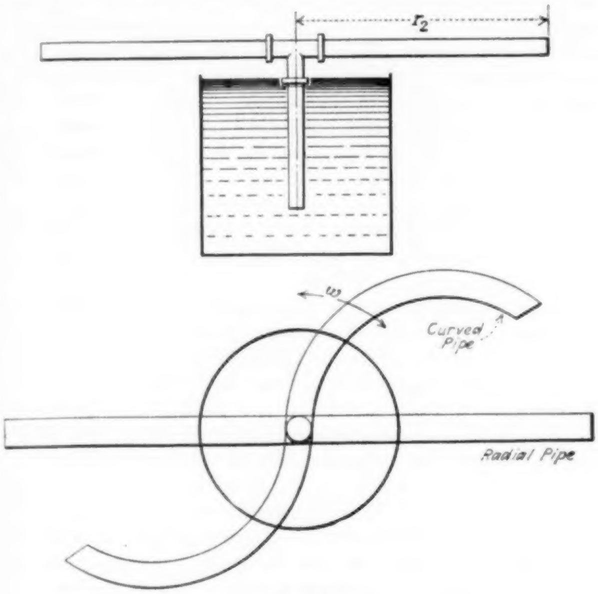


Fig. 22

It can be shown[5] that if the water were introduced at the center at atmospheric pressure and the pressure at the exit of the tube were also atmospheric, friction being neglected, the water will discharge with a relative velocity $w_2$ equal to the peripheral speed $u_2$. This is true not only for radial vanes, but for either forward- or backward-curved vanes as well, under the above conditions. In such cases, it is evident that the total energy given to the water is represented by the absolute velocity of discharge $C_2$ and equal to $\dfrac{C_2^2}{2g}$ per each pound of water. We may have three cases as shown in Fig. 23.

In the first case the water would discharge with a relative velocity $w_2 = u_2$ and in the opposite direction; hence the two would cancel, and the energy given to the water would be zero. In the second case the relative velocity $w_2 = u_2$ is radial and the absolute velocity makes an angle of 45 deg. with the tangent and $C_2 = \sqrt{2}\, u_2$. The kinetic energy per pound of water is therefore $\dfrac{C_2^2}{2g} = \dfrac{u_2^2}{g}$. In the third case the relative velocity $w_2 = u_2$ is directed forward in the same direction as $u_2$, whence $C_2 = 2u_2$ and the total head is:

$$\frac{C_2^2}{2g} = \frac{2u_2^2}{g}$$

Apparently, then, the energy given to the water may vary from zero to $2u_2^2/g$ according to the curvature of the vanes.

Now considering the application of this to Equation [30],

$$H = \frac{u_2^2}{g} + \frac{u_2 w_2}{g} \cos \beta_2$$

when $\beta_2 = 0$, $\therefore \cos \beta_2 = +1$; and since $u_2 = w_2$

$$H = \frac{u_2^2}{g} + \frac{u_2^2}{g} = \frac{2u_2^2}{g}$$

This is exactly the value called for by the kinetic theory given above. Or, when $\beta_2 = 180$ deg., $\cos \beta_2 = -1$, and since $u_2 = w_2$,

$$H = \frac{u_2^2}{g} - \frac{u_2^2}{g} = 0$$

This again shows the agreement of the kinetic theory with the author's Equation [1′]. As was shown before, the author's Equation [1′] could be written as

$$H = \frac{u_2^2}{g} + \frac{u_2 w_2}{g} \cos \beta_2,$$

where $w_2$ is the relative velocity at discharge from the impeller. Now from the discharge diagram, Fig. 24, and since under the conditions of free radial acceleration $w_2$ is equal to $u_2$ in magnitude, and the entire energy given to the water is represented by the kinetic energy of the absolute velocity $C_2$, it is clear that

$$H = \frac{C_2^2}{2g}$$

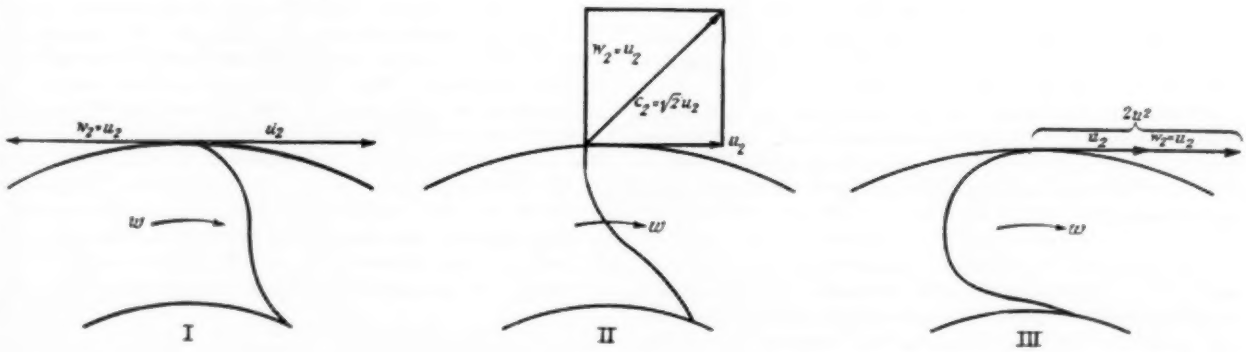


Fig. 23

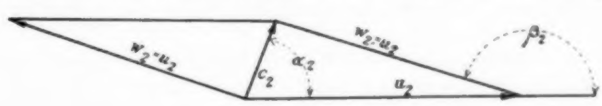


Fig. 24

Now $C_2^2 = u_2^2 + w_2^2 - 2u_2 w_2 \cos (180 - \beta_2)$, or

$C_2^2 = u_2^2 + w_2^2 + 2u_2 w_2 \cos \beta_2$. Now since $u_2 = w_2$

$C_2^2 = 2u_2^2 + 2u_2 w_2 \cos \beta_2$, and dividing by $2g$,

$$\frac{C_2^2}{2g} = \frac{2u_2^2}{2g} + \frac{2u_2 w_2}{2g} \cos \beta_2, \text{ or}$$

[5] See paper by the writer, "A New Theory and Analysis of the Centrifugal Pump," Proc. A.S.C.E., Oct., 1927.

$$\frac{C_2^2}{2g} = \frac{u_2^2}{g} + \frac{u_2 w_2}{g} \cos \beta_2$$

which is identical with the writer's Equation [30] and can be easily changed to the author's Equation [1].

This should make it clear that the $H$ in the author's Equation [1'] is nothing more or less than the kinetic energy $\frac{C_2^2}{2g}$ and holds only for such a kinetic pump. It goes without saying that free radial acceleration is never realized in any actual centrifugal pump, nor is it even closely approached; hence the observed difference. The theory proposed by the author is more nearly that of a mechanical lawn sprinkler than of a modern centrifugal pump.

W. M. White.[6] The author has made a real effort to find a solution that would be of benefit to the designer. The only criticism of the method is that it is too complicated. There is no time in the manufacturing plant to analyze the various pumps constructed and tested even in accordance with the analytical method.

The writer cannot agree with the author that the flow occurs as the arrow indicates in Fig. 1. There may be a tendency to flow in that direction, and there is a difference in velocity across the channel formed by the two vanes of the impeller, but that there is an actual reversal of flow is open to doubt.

The form of casing illustrated in Fig. 19 is interesting, but the author's statement that "the discrepancy between the theoretical results of the classical one-dimensional theory used in calculating centrifugal pumps and the actual practice forces us to introduce correctional factors that can only be deduced from tests," leads one to doubt that that is the final proper design of a spiral casing. We must still do what we have done for 25 years: depend on tests and formulas to direct us in design.

Nevertheless, the author deserves credit for the painstaking work he has done. The paper will undoubtedly lead to considerable study in the direction indicated, with an ultimate result of securing a method of design that can be used in the rush of modern business.

A. L. McHugh.[7] The writer cannot agree with the statement of Mr. White that the method outlined by the author is too laborious to be useful. A paper such as this one on centrifugal pumps, setting forth theories and methods of analysis, is a step in the right direction. It will lead to studies that will be helpful to industry. There have been too few papers of this character before the Society.

The writer has made a few analyses of impellers made by his company, according to the author's method. On the whole the theory seems sound, and good results can be obtained with it.

M. G. Robinson.[8] The writer's work deals with air compressors and not with centrifugal pumps, although fundamentally the air compressor is the same machine as the centrifugal pump. It is well known that due to a finite number of blades in an actual impeller, the pressure developed by a centrifugal air compressor is not as high as the usual classical theory would indicate. There is every reason to believe that the average angle which the relative velocity of the fluid makes with the peripheral velocity of the wheel, is less than the angle of the blade as constructed.

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In the author's example, a 20-deg.-blade centrifugal pump performs as if it had an angle of 14 deg. 45 min. This is a reduction of 25 per cent with a correspondingly large reduction in the pressure-generating capacity of a wheel of a given diameter running at a given speed. In centrifugal compressors, due to the relatively low density, and consequently higher speed required, angles as low as 20 deg. are practically unknown, the usual range being 90 deg. to 45 deg. Experience points to the fact that with such steep angles the decrease in the actual blade angle is not apt to be so pronounced.

In connection with a series of tests made at Lynn on air compressors with casings of two types, the following conclusion was arrived at: That the use of a casing with a volute with guide vanes causes less of a decrease in the blade angle than there would be when using a casing without guide vanes. The writer would like to inquire if the author has had any similar experience with a centrifugal pump.

The reason why the actual effective angle of a blade should be determined is to enable the manufacturer to show the entire characteristic curve of the machine; It is fairly easy to get a guaranteed performance for one point only, but in order to draw the entire curve from no load to zero pressure, it is absolutely necessary to know what the actual effective blade angle is, not judging entirely from the construction of the blade.

Sanford A. Moss.[9] A fundamental criticism could be applied to all methods of analysis similar to those set forth by the author. The centrifugal pump has one point of maximum efficiency, where vane angles and passage areas are correct and at which all losses are reduced to a minimum. At that point it is desirable to know the losses. If they can be determined and reduced the pump can be improved. At other points the losses are increased, due to incorrect angles and areas, and sometimes due to absurd conditions. When an attempt is made to analyze the performance by using the entire performance curve, a handicap is encountered which prevents one from obtaining the losses at the point of best efficiency by reason of the absurd conditions at the extreme points.

The Author. The equation of the total head

$$H = \frac{1}{g}(u_2 C_{u2} - u_1 C_{u1}) \quad \ldots\ldots\ldots\ldots\ldots [1]$$

is nothing else but a special expression of the law of conservations of energy. It simply states that if a fluid containing the energy $E_1$ enters a system (in our case the impeller) and leaves this system with the energy $E_2$, the difference $E_2 - E_1$ must have been given to the fluid by this system (losses excluded) regardless of the nature of process within the system. This equation is therefore of a very general and fundamental character and expresses the energy given to the water by the impeller independently of the particular design of the impeller, or the particular conditions under which the impeller is working. Equation [1] gives the total head of a kinetic-pump runner as well as of an impeller surrounded by a pressure chamber (centrifugal pump). It expresses the total head of a radial pump, where a centrifugal force is acting, as well as of a purely axial pump.

It is therefore not surprising at all that when Professor Sherzer applies this equation to the special case of the kinetic pump where no difference of pressure is generated between the entrance and exit of the impeller, he finds that it reduces to the value $\frac{C_2^2}{2g}$, the total head of a pump under these particular conditions.

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But the author fails to understand how Professor Sherzer concludes from this evident fact that Equation [1] is therefore *only* to be applied to a kinetic pump and not applicable to a pump working under other conditions. To clear the situation, he will indicate roughly how Equation [1] can be derived, proceeding from the law of energy and with assumptions entirely different from those of the kinetic pump. In other words, assume that the pressure at the exit of the impeller is greater than at the entrance, and that the relative velocity $w_2$ at exit is not equal to the peripheral velocity $u_2$.

In the following, in speaking of the energy of the liquid we shall always have in mind the energy of the unit of weight of this liquid.

Let $\gamma$ be the specific gravity of the liquid (see Fig. 25), and $C_1$ and $P_1$ the velocity and pressure of the liquid at entrance (the pressure measured from atmospheric). The liquid before entering the impeller then possesses the energy

$$E_1 = \frac{C_1^2}{2g} + \frac{P_1}{\gamma}$$

If $C_2$ and $P_2$ are the velocity and pressure of the liquid after leaving the impeller, its corresponding energy is

$$E_2 = \frac{C_2^2}{2g} + \frac{P_2}{\gamma}$$

The law of energy states that the increase $E_2 - E_1$ in energy can only have come through the action of the impeller. The impeller has therefore created the total head

$$H = \frac{C_2^2 - C_1^2}{2g} + \frac{P_2 - P_1}{\gamma} \quad \text{. . . . . [a]}$$

Now in a centrifugal pump we have two sources of creating pressure within the channel of the blades. The first is through diffusion, changing velocity into pressure—in our case, reducing the relative velocity $w_1$ at entrance to the relative velocity $w_2$ at exit, with a corresponding gain in pressure of $\frac{w_1^2 - w_2^2}{2g}$. The second is through centrifugal force, the corresponding creation of pressure in this case being $\frac{u_2^2 - u_1^2}{2g}$.

Therefore

$$\frac{P_2 - P_1}{\gamma} = \frac{w_1^2 - w_2^2}{2g} + \frac{u_2^2 - u_1^2}{2g} \quad \text{. . . . . . . . . . . [b]}$$

The total head is now

$$H = \frac{C_2^2 - C_1^2}{2g} + \frac{w_1^2 - w_2^2}{2g} + \frac{u_2^2 - u_1^2}{2g} \quad \text{. . . . . . . [c]}$$

The energy contained in the liquid at entrance may come from an outside source, or may have been given to the water by the action of the atmospheric pressure. In the latter case $(P_1/\gamma)$ is negative and Equation [a] shows that the impeller has to create the corresponding energy. From the entrance and exit velocity diagrams of Fig. 25 we conclude that

$$w_1^2 = u_1^2 + C_1^2 - 2u_1 C_1 \cos \alpha_1$$

$$w_2^2 = u_2^2 + C_2^2 - 2u_2 C_2 \cos \alpha_2$$

Substituting these values in Equation [c],

$$H = \frac{1}{g}(u_2 C_{u2} - u_1 C_{u1}) \quad \text{. . . . . . . . . . . . . . [1]}$$

which is the basic equation of the total head of this paper. The foregoing shows that Equation [1] is a general equation embracing all cases of pumping conditions and including as a special case the kinetic pump referred to by Professor Sherzer. For the kinetic pump $P_1 = P_2$ and Equation [b] then gives $\frac{u_2^2 - u_1^2}{2g} = \frac{w_2^2 - w_1^2}{2g}$. In case the water enters centrally as Professor Sherzer assumes, $u_1 = 0$ and $w_1 = 0$, and therefore $u_2 = w_2$. And Equation [a] for $P_1 = P_2$ and $C_1 = 0$ shows that for this case $H = C_2^2/2g$.

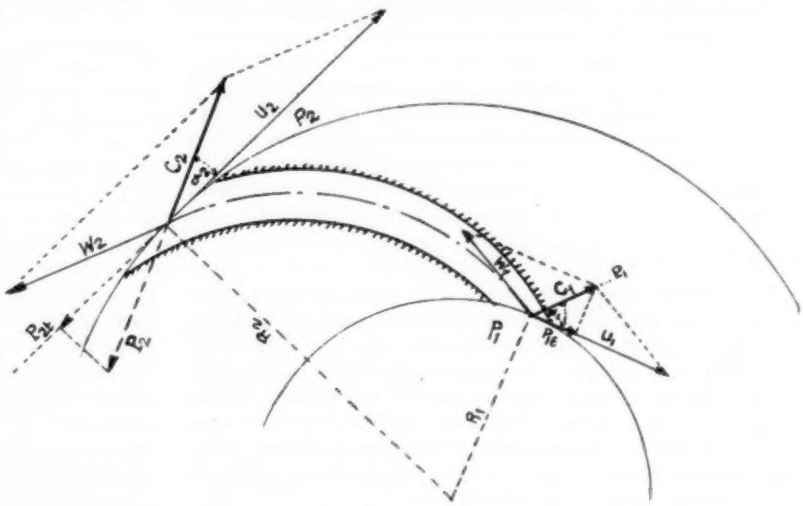


Fig. 25

In order to make the value $u_1 C_{u1} = 0$, Professor Sherzer has to assume that the water must enter the impeller at the center. But this assumption is not necessary at all and the author did not have to make use of it in developing his equation. The water may enter the impeller at any distance from the center. If it arrives with a velocity $C_1$ at an angle $\alpha_1$ with the peripheral velocity, Equation [1] indicates the corresponding created head. If the velocity $C_1$ is normal to the peripheral velocity the head is $H = 1/g\ u_2 C_{u2}$, even if the water enters the impeller at a distance from the center.

In his discussion Professor Sherzer states that it is hard to see how the entrance rotation could decrease the head. In his opinion it could only increase it. And later he says: "In the centrifugal pump all the angular momentum possessed by the water at discharge from the runner has been obtained from it. For this reason the term $u_1 C_{u1}$ does not apply." To clear away this objection let us consider the equation of the angular momentum obtained by dividing the equation of the total head by the angular velocity. (See Fig. 25.)

$$M = \frac{1}{g}(r_2 C_{u2} - r_1 C_{u1}) \quad \text{. . . . . . . . . . . . . . . [d]}$$

The impulse force per unit of weight at the exit is equal to $\frac{1}{g} C_2$ and acts in the direction of $C_2$. The corresponding reaction force on the impeller is equal to this impulse force but in an opposite direction. The tangential component of the reaction force is therefore equal to $\frac{1}{g} C_{u2}$ and is opposite to the rotation. This

force acts as a resistance to the rotation of the impeller, and the impeller in overcoming it has to do the work $\frac{1}{g} C_{u2} \cdot u_2$. At the entrance, however, the impulse force of the water is $\frac{1}{g} C_1$ in the direction of $C_1$, and the reaction on the impeller is in the same direction. The tangential component of this force is $\frac{1}{g} C_{u1}$ in the direction of the rotation. This force therefore supports the impeller in its action and does the work $\frac{1}{g} C_{u1}u_1$. The work which the impeller alone has done is therefore the difference $\frac{1}{g} (u_2C_{u2} - u_1C_{u1})$.

Stated in another way, the impeller assisted by the atmospheric pressure gives to the water the velocity $C_1$ before it enters the impeller. If this water enters the impeller so that $C_1$ has a tangential component, then it is able to return to the impeller a part of the energy it received. Therefore the energy which the water has received from the impeller is diminished by this amount. In case, however, that the water enters the impeller so that $C_1$ is normal to the tangential direction, then it is not able to return to the impeller any energy, and the total energy received by the water from the impeller is then $\frac{1}{g} u_2C_{u2}$.

The equation of the total head is based on certain assumptions which do not conform well with the actual pump as shown in the paper. For this reason the equation had to be transformed and those physical factors introduced which the equation neglected. As far as the author knows, all the physical factors influencing this equation have been considered in the paper. He thinks that the development of Equation [1] clearly shows that Professor Sherzer's idea that this equation is only applicable to the kinetic pump is not sound.

In regard to the criticism made by Professor Sherzer as well as by Mr. White concerning the whirl flow, there seems to be quite considerable misunderstanding on this subject. The whirl flow is nothing else but the hydrodynamic explanation of how a runner with only a small number of blades is able to transmit the necessary forces to the water. Fig. 1 of the paper does not represent the actual flow of the water through the channels of the blades, but only a component of this flow. In other words, the flow through the channel is composed of the main flow and this whirl flow. At normal rates of flow the velocity due to the main flow is much higher than the backward velocity of the whirl on the acting side of the blade. Therefore a reversal of flow does not occur. But at small rates of flow this whirl velocity may be higher and then a reversal takes place. The whirl flow is not some kind of an eddy current connected with energy losses. It exists whenever energy is transmitted from the blades to the water and it exists because of this fact. The result is that a runner with only a small number of blades is not able to create as high a pressure as one with an infinite number of blades would be able to do under the same conditions. The whirl flow disappears only when there is no transmittance of energy to the water; that is in the case of a purely radial flow through the impeller. There is a case where the whirl flow theoretically does not exist and this is in the purely axial pump. Here exertion of forces by the blades on the water is only possible because of change of directions of the flowing water—a reason why the axial pump is so much more unstable in its creation of pressure than the centrifugal pump.

Mr. White's remarks about the proper design of the spiral casing are not quite clear to author. The paper shows that for a pump of given conditions of capacity and head the volute section is determined; but without any preference being given to a particular shape of casing. The only condition imposed is that in calculating the volute only the actual section passed by the water shall be considered. Tests will always be necessary to the development of the centrifugal pump, and one of the main tasks of the paper is to indicate methods of extracting from those tests all the knowledge which is not readily apparent.

Mr. Robinson's experiences concerning the difference of blade angle and fluid angle in air compressors with and without guide vanes are very interesting. The author has not had a chance as yet to analyze many guide-vane pumps. But the fact that in a guide-vane compressor the angle difference is smaller is not surprising. The difference between blade angle and fluid angle may be traced to two sources. The first is the difference which takes place within the channel of the blades and forces the fluid to leave the blade walls. The second is the reaction of the flow in the casing on the flow in the impeller. In the case of the guide-vane compressor this reaction is probably prevented and the angle difference therefore reduced.

Replying to Dr. Moss, the author would say that the method described in the paper does not employ the entire performance curve for the purpose of analysis, but only a very narrow range around the points of maximum efficiencies. In a centrifugal pump there does not exist just one point where all losses at the same time are minimum. The point of best hydraulic efficiency is different from the point of maximum total efficiency. And the point of maximum total efficiency does not necessarily correspond with the point where the shock losses are a minimum. So the use of the range of the curve where all these optimum points are located seems therefore to be quite justified.

# Centrifugal Pumps

## General Considerations Regarding Losses, Disk Friction, Specific Speed, Etc.—Principles Governing Design of Volute, Suction and Delivery Pipes, Impeller, Bearings and Glands, Priming Apparatus, Etc.—Materials of Construction

By H. T. DAVEY,[1] BEXLEY HEATH, KENT, ENGLAND

ALTHOUGH originally regarded as a means of raising large quantities of water against low heads with a fair degree of efficiency, centrifugal pumps of modern design are used for a variety of purposes, and in many cases, using high speeds of rotation, high lifts have been obtained. This is particularly so with the turbine pumps, in which the highest efficiencies are obtainable.

It is obvious that a pump can only be designed to give efficient results under one set of working conditions, and therefore it must always be run at the designed speed if best results are to be obtained. Centrifugal pumps are therefore best suited to work of constant character.

Of the many uses to which these pumps are put, the following may be regarded as the most important:

(*a*) Irrigation
(*b*) Drainage
(*c*) Circulation
(*d*) Suction dredging.

For irrigation purposes the greater market is in countries where the rainfall is uncertain or comes at one particular season of the year. In low-lying country, where rain is abundant, centrifugal pumps are used for drainage, as in Holland, where some of very large size are in use. Many pumps used for these purposes have delivery pipes five and six feet in diameter and are therefore capable of dealing with large quantities of water. For dredgers, special material must be used for the pumps on account of the solid matter which is drawn through them with the water.

The efficiency of a centrifugal pump is dependent upon the extent to which the kinetic energy of the fluid at discharge from the disk can be changed into pressure energy in the volute or casing. The velocity of the fluid leaving the disk will be high, and therefore, in order to prevent losses, or at least minimize them, the volute must be designed to gradually reduce this high velocity of discharge to that of the fluid in the pipes; unless this change is gradual, energy will be lost by the setting up of eddies in the volute, which will lower the efficiency. The usual form of pump casing is spiral, the cross-sectional area increasing toward the delivery branch, the area being proportional at any section to the quantity of fluid flowing through it.

To secure the best results and highest efficiency, the fluid must be taken into the suction pipe at a low velocity and delivered also at a low velocity, the maximum speed being obtained in the pump.

Centrifugal pumps are made with single and double inlets. The latter type seems preferable since end thrust on the shaft is eliminated, and therefore no special precautions are necessary, the disk being balanced by the incoming water. In actual practice, however, the single-inlet type is often manufactured, particularly for very light duties; the cost of manufacture of this type of pump is somewhat less than that of the double-inlet type.

For lifts over 100 ft., multi-stage pumps are manufactured, having two or more impellers, according to the duty which the pump is called upon to perform; but for lifts up to 100 ft. the single-impeller pump is efficient.

### Calculations

Throughout this paper the following symbols will be used:

$\omega$ = angular velocity of disk, in radians per second
$r_1$ = radius of periphery of eye, in feet
$r_2$ = radius of periphery of disk, in feet
$u_1$ = linear velocity of periphery of eye, in feet per second
$u_2$ = linear velocity of periphery of disk, in feet per second
$u_a$ = absolute velocity of discharge from disk, in feet per second
$\alpha$ = angle of vane tip at entry
$\gamma$ = angle of vane tip at exit
$v$ = velocity of discharge in feet per second
$V_r$ = radial velocity of flow at entry, in feet per second
$V_R$ = radial velocity of flow at exit, in feet per second
$V_V$ = velocity of flow in volute, in feet per second
$V_W$ = velocity of whirl at periphery of disk, in feet per second
$v_d$ = velocity of flow in delivery pipes, in feet per second
$v_s$ = velocity of flow in suction pipes, in feet per second
$Q$ = quantity of water flowing, in cubic feet per second (total)
$W$ = weight of 1 cubic foot of water = 62.4 lb.
$g$ = acceleration due to gravity = 32.2 ft. per sec. per sec. [approx. in London, 32.18]
$H$ = total height in feet to which water is raised by pump = head
$H_m$ = total head against which pump is working, in feet, or the manometric head
$H_P$ = head of water lost in pipe friction, in feet
$L_h$ = hydraulic losses
$L_m$ = mechanical losses.

Fig. 1 shows a typical velocity diagram for a centrifugal pump of the usual construction, and employs a number of the above symbols.

Of the three efficiencies usually considered in connection with centrifugal pumps, the working efficiency, or what may be called the overall efficiency, is the most important, from several points of view. This efficiency is the ratio of the work done by the pump to the work put into it.

$$\text{Working efficiency } \eta_W = \frac{H_m}{\dfrac{V_W u_2}{2g} + L_h + L_m}$$

$H_m$ is equal to $H + H_P + v^2/2g$ and is termed the manometric head. Also,

$$\left.\begin{array}{l}\text{Turning moment on shaft}\\ \text{equivalent to change in}\\ \text{angular momentum per sec.}\end{array}\right\} = \frac{WQ}{g}(V_W r_2 - V_W r_1) \text{ lb-ft.}$$

$$\text{Work done per second} = \frac{WQ}{g}(V_W r_2 - v_w r_1)\omega \text{ ft-lb.}$$

[1] Associate-Member, Institution of Mechanical Engineers.

Contributed by the Hydraulic Division and presented at the Annual Meeting, New York, December 5 to 8, 1927, of The American Society of Mechanical Engineers.

As it is not usual to provide guide vanes in the eye, the velocity of whirl $v_w$ will be zero; this assumes that the water is not made to rotate by friction. Thus assuming radial flow, and since $\omega = u_2/r_2$,

$$\text{Work done per second} = \frac{WQ}{g} V_W u_2 \text{ ft-lb.}$$

and

$$\text{Work done per lb. of water} = \frac{V_W u_2}{g} \text{ ft-lb.}$$

The ratio of $H_m$ to the work done on the water per pound gives the manometric efficiency $\eta_m$.

$$\eta_m = \frac{H_m g}{V_W u_2}$$

From the velocity diagram, Fig. 1, $V_W = u_2 - V_R \cot \gamma$

$$\therefore \eta_m = \frac{H_m g}{u_2(u_2 - V_R \cot \gamma)}$$

The expression thus obtained does not include any losses,

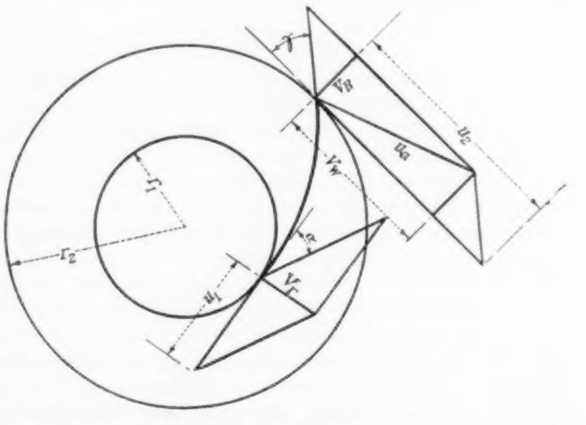


Fig. 1 Typical Velocity Diagram for a Centrifugal Pump of the Usual Construction

and if therefore the hydraulic losses are added, the hydraulic efficiency $\eta_h$ can be obtained:

$$\eta_h = \frac{H_m}{\dfrac{V_W u_2}{g} + L_h}$$

## Losses

The losses in a centrifugal-pumping installation are of two kinds, namely, hydraulic and mechanical. Those losses which arise due to the presence of the fluid may be called hydraulic losses, while losses such as friction at bearings may be called mechanical losses.

In a centrifugal pump and also in the pipe lines connected with it, certain losses will occur, some of which must be taken into account when designing the plant, since they often reach considerable proportions. Every effort must of course be made to keep such losses a minimum.

In the pipe lines there will be friction losses, which can be closely estimated by means of the Darcy formula:

$$H_P = Z\left(1 + \frac{1}{12d}\right)\frac{v^2}{2g} \cdot \frac{4l}{d}$$

In this case $l$ = length of pipes in feet
$d$ = diameter of pipes in feet
$Z$ = constant depending upon the condition of the pipes. For old pipes $Z = 0.01$; for new ones, $Z = 0.005$, the material being cast iron
$v$ = velocity of flow in pipes in feet per second.

Sudden enlargements of pipes, or contractions, will produce hydraulic losses, and should therefore be avoided. Right-angled bends should also, where possible, be avoided.

Hydraulic losses will also occur at discharge. If $v_d$ is the velocity at discharge, the energy lost per pound of water = $v_d^2/2g$ ft-lb.

Again, losses will occur when the water leaving the disk meets the water flowing in the volute. The loss from this cause will be:

$$\frac{(u_a - V_V)^2}{2g} \text{ ft-lb. per lb.}$$

## Disk Friction

The friction of the disk rotating in the fluid also contributes to a large extent toward the losses.

One of the chief influencing factors in regard to the disk friction is the clearance between the faces of the disk and the casing. It has been shown by experiment[3] that, as the clearance increases, so the friction increases, and therefore the

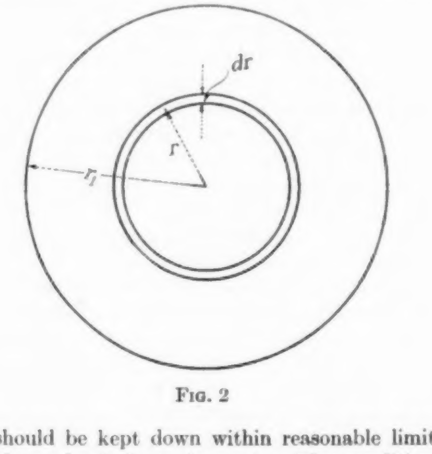


Fig. 2

clearance should be kept down within reasonable limits, compatible with mechanical requirements. The condition of the surface of the casing and disk also has some effect upon the friction, but it is very doubtful if the extra cost of producing highly finished machined surfaces pays, since ordinary painted and varnished faces seem to be just as satisfactory, and more so from some points of view. The viscosity of the fluid will also affect the friction, as will also the velocity of the disk.

Consider a thin strip of the disk with a width $dr$ (Fig. 2), and situated at radius $r$ from the center. Also let

$\rho$ = resistance per square foot of surface per unit velocity
$V_f$ = velocity of fluid relative to disk, in feet per second
$r_1$ = radius of disk in feet
$u$ = velocity of strip $dr$ of disk relative to velocity of fluid, in feet per second.

It has been established by experiment that the friction varies as $u^n$, where $n$ depends upon the clearance of the disk, etc. It is, however, sufficiently accurate for most practical purposes to take $n = 2$, and therefore the friction varies as $u^2$. Also

[3] Proc. Inst. C. E., vol. 80 (1885).

the velocity of the strip will be proportional to its radius $r$, therefore $u = V_f r/r_1$.

Total resistance of wetted surface $= \rho\, 2\pi\, r dr u^2$

$= \rho\, 2\pi\, r^3 dr V_f^2/r_1^2$

Moment of this force $= \rho\, 2\pi\, r^4 dr V_f^2/r_1^2$

Moment of total frictional force on disk $= \rho\, 2\pi\, V_f^2/r_1^2 \int_{r=0}^{r=r_1} r^4 dr$

$= {}^2/_5 \pi\rho V_f^2 r_1^3$

Turning moment due to friction on both sides of disk $= {}^4/_5 \pi\rho V_f^2 r_1^3$

Work lost in friction $= {}^4/_5 \pi\rho V_f^2 r^3 \omega$ ft-lb. per sec.

$= {}^4/_5 \pi\rho V_f^3 r_1^2$ ft-lb. per sec.

The values of $\rho$, as previously mentioned, will depend on the side clearance and the condition of the surfaces of both the disk and the casing. There is, however, a very considerable difference in values for different surfaces and different clearances, the range being from about 0.0132 lb. down to 0.0031, the higher values for the rough surfaces.

The effect of putting vanes on to the disk is to increase the friction. There will also be slight frictional loss due to the flow through the vanes. This will, however, be comparatively small. The friction of the water flowing round the volute will also account for some loss of power, and can be approximately computed from the length of the volute and its diameter.

The above losses are those of most importance, and must be considered when calculating the hydraulic efficiency. There are of course other losses which may occur, such as slip, etc., all tending to reduce the efficiency.

The mechanical losses will depend upon the type and condition of the bearings, and also the kind and condition of packing used in the stuffing boxes. The fit of the impeller in the casing will also have some effect. The actual magnitude of these losses can be determined by running the pump without load and determining the actual power absorbed.

### Speed at Which Pumping Commences

A centrifugal pump will not begin to pump until the speed of the disk is sufficient to create a pressure difference through the disk greater than the total pressure head against which the pump is to work. In order that the pump shall commence working, the angular speed $\omega$ of the disk must be such that $\omega^2(r_2^2 - r_1^2)/2g$ is greater than the total head $H_m$.

### Specific Speed

With respect to a centrifugal pump, the specific speed is the speed at which an exactly similar one of reduced size would require to run in order to deliver 1 cubic foot per second against a total head of 1 foot and give maximum efficiency.

If $N$ = number of revolutions per minute of an actual pump
$Q$ = discharge in cubic feet per second
$H_m$ = total head against which pump operates, in feet, and
$N_s$ = specific speed in revolutions per minute,

then

$$N_s = \frac{N\sqrt{Q}}{H_m^{5/4}}$$

According to various authorities,[3] the specific speed for maximum efficiency should lie between 80 and 240; hence, accepting these conditions, pumps should be designed so as to have specific speeds within this range.

[3] L. T. Moody, *Mechanical Engineering*, April, 1921, and S. F. Sherzer, *Engineering News-Record*, June, 1921.

## GENERAL PRINCIPLES OF DESIGN

Broadly speaking, there are three types of centrifugal pumps in general use:

*a* Single-inlet
*b* Double-inlet single-stage, and
*c* Multiple-stage.

For low lifts and small capacity, the single-inlet pump is the most used, while the separate units in the multi-stage pumps are usually of this construction. As previously mentioned, the cost of production is less than that of the double-inlet type, and the casing more easily made. For small oil pumps and cooling-water circulating pumps for internal-combustion engines, this type is very common. Owing to the end thrust set up by the incoming water, thrust bearings are necessary with this type.

For greater lifts up to 100 ft. and high capacity the double-inlet single-stage pump is largely used, while for high lifts, from 100 ft. to 2000 ft., for best results the multiple-stage pump is most satisfactory. The end thrust is also eliminated in the double-inlet construction, the rotor being balanced by the incoming water.

### The Volute of Casing

Generally, the pump casing is made in two parts, this construction being necessary in order to get the disk into position, and also for cleaning purposes. The joint line is made in one of the four following ways:

1 On a center line in the plane of the pump
2 On a horizontal center line in a plane through the axis of rotation
3 A side cover is provided, the joint line of which is arranged conveniently on the side of the pump
4 As in 3, but with one cover on each side of the disk.

Each method has its good and bad points, but the question is largely one for the judgment of the designer. It may, however, be stated that a single side cover gives an inexpensive job, and is satisfactory for many purposes.

It is important to at once realize that the efficiency of a centrifugal pump depends largely upon the design of the volute. Its duty is to change into pressure energy the kinetic energy of the fluid given to it by the impeller. With this object in view, three principal types of casings have been manufactured:

*a* Volute with whirlpool chamber
*b* Plain volute or spiral casing, and
*c* Casing with guide vanes.

The first type has now gone out of existence, so far as practical work is concerned, but undoubtedly small pumps, well made, and provided with a vortex or whirlpool chamber, gave good results and worked efficiently.

The second type is very common for low and moderate lifts, and when well designed, works very efficiently.

The third type, applied to turbine pumps, is used for very high speeds and generally for high lifts. These represent the most efficient type of pump. Small rotors are used for this purpose.

It has been established by practical tests that the best results are obtained when the velocity of flow in the volute is between $0.3\sqrt{(2gH_m)}$ and $0.4\sqrt{(2gH_m)}$. Since the whole of the water pumped has to pass through the throat, the area here should be such as to allow full flow at a velocity not exceeding that selected from the above values. The area of any cross-section

is proportional to the quantity flowing through it, and therefore the areas of the volute at points *a*, *b*, *c*, *d*, *e*, *f*, Fig. 3, must be proportional to $^1/_4$, $^3/_8$, $^1/_2$, etc., respectively, of the total quantity of water flowing. When such is the case, the velocity

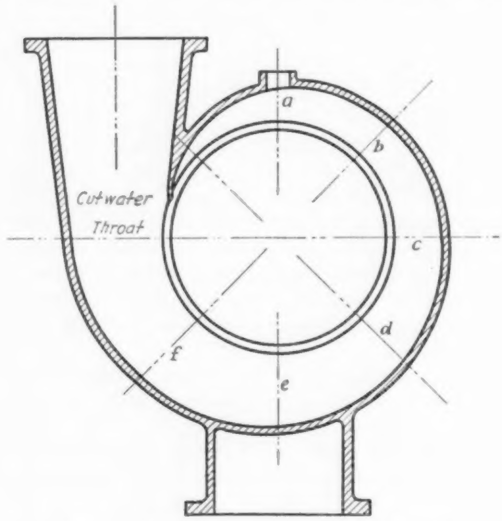


Fig. 3 Diagrammatic View of a Volute

of flow in the volute will be constant. A more or less circular section is maintained throughout. Fig. 4 shows a form of volute cross-section which has been adopted by some makers, but in the opinion of the author, this section, which gradually changes from a very shallow segment to a full circle at the throat, is not desirable since "dead water" tends to collect and lag in the side pockets of the section.

In order to prevent the water flowing through the throat being driven round the casing, a stop or cutwater is necessary. This usually forms part of the main volute casting, and will be clearly seen on reference to Fig. 3; there should be a good clearance between the cutwater and impeller, otherwise vibration during working may occur.

In the case of the turbine pump, the main casting is arranged so that guide vanes can be fitted. These guide vanes are provided so that the area of waterway from the outlet of the disk gradually increases outward, and thus the velocity of discharge falls. In these pumps, the tips of the vanes on the disk are often radial at discharge. The cost of providing these guides is of course considerable, but very high efficiency can be obtained, and if high speeds are used, large quantities of water can be pumped with a comparatively small machine.

## Delivery Pipes

In order to reduce the velocity of flow along the delivery pipes and obtain as much pressure energy as possible from the available kinetic energy, the usual practice is to enlarge the delivery branch of the pump to such an extent that the velocity of flow in the pipes does not exceed 8 or 10 ft. per sec. A common rule is to make the delivery-pipe area twice that of the throat, but there is no general rule in regard to this point. In several pumps with which the author has had experience, the velocity of flow in the pipes has been about half that of the water in the volute. These pumps are giving satisfactory results.

In many cases the delivery pipes have been made abnormally large, in order to reduce the velocity of flow to within 2 or 3 ft. per sec., but the practice is unusual, since large pipes add greatly to the initial cost, and little is to be gained from it. It is also known that, for high lifts, the efficiency falls off when the speed is too low.

When the delivery pipes are short, it is common practice to gradually increase their diameter, so that the velocity at discharge is low, say, about 2 or 3 ft. per sec. In cases where the pipes are long, the delivery branch from the pump is enlarged to give a flow of about 8 or 10 ft. per sec., and a bell mouth is fitted at the delivery end of the pipes. (Fig. 5.)

## Suction Pipes

Wherever possible, the suction pipe should be short. The low efficiency often obtained is due to long suction pipes, air leaks, etc. The best pumps obtainable will not work satisfactorily, if at all, with suction heads greater than 25 or 27 ft.

As with the delivery pipes, the suction is often such that

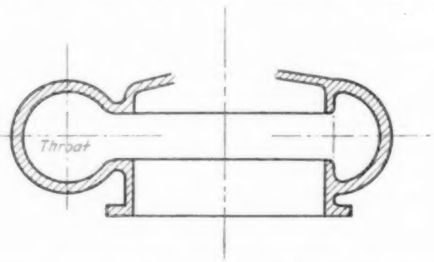


Fig. 4 Cross-Section of a Volute. Segmental Section Changing to Circular at Throat

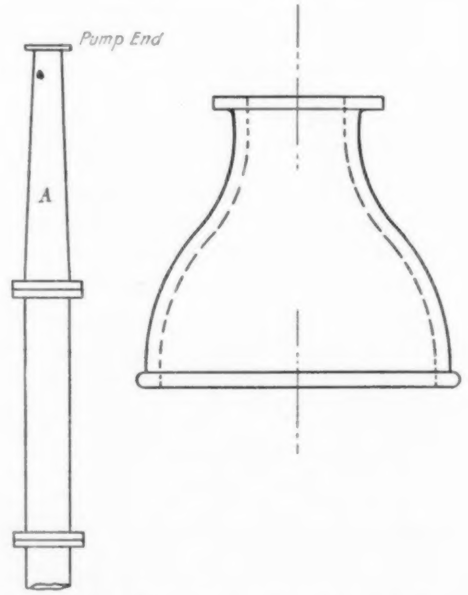


Fig. 5 Reducer for Pump End of Pipe Line and Bell Mouth for Suction and Delivery Pipe Ends

(To reduce friction in long suction pipe lines large-diameter pipes are used. Velocity is increased toward pump by the reducer A in sketch at left.)

the water enters at very low speed, and due to a gradually decreasing pipe diameter, it increases toward the pump. The best results will be obtained if the velocity of the water entering the suction pipe is about 3 ft. per sec., and on reaching the pump is increased to about 6 or 8 ft. per sec.

Many pumps will be found to have suction pipes of the same size as the delivery, but conditions as given above will generally secure the most satisfactory results.

In regard to the suction branches to the eye of the disk, it is good practice to make their combined area slightly in excess

of the suction-pipe area. These should, however, not be excessively large and should lead in as straight as possible, so as to avoid air locks due to pocketing.

### Pipe Diameters, Lengths, Etc.

When fixing pipe diameters it is well to keep in view the standard stock sizes manufactured, since if these have to be specially made, the initial cost is increased.

### The Impeller, Disk, or Rotor—General

Broadly speaking, there are three types of disks in general use:

*a* Single-sided, open or shrouded
*b* Double-sided, open type, and
*c* Double-sided, shrouded type.

The single-sided disk is used largely for single-inlet pumps working against heads up to 100 ft., and also for the large multi-stage pumps fitted with guide vanes in volute. Disks of this type are not generally directly balanced by the water, as is the case with the double-inlet disk, but require special means for balance, such as ball thrust races, or collars, although in some cases they are balanced hydraulically.

The double-sided disk is employed in double-inlet pumps, and is balanced directly by the water flowing into the eye. These disks may be either open or shrouded. If the former is employed, then the disk must form a neat running fit within the casing. If the latter is used, then a fairly large clearance can be made. With regard to this point, it should be borne in mind that the disk friction will increase as the clearance increases, and hence the clearance should be a minimum compatible with mechanical requirements. As far as efficiency goes, there is a tendency for excessive slip to occur with the unshrouded disk, which affects the efficiency adversely.

From the point of view of manufacture, the open type is undoubtedly the easiest and cheapest, since it is much easier to mold, and when cast the channels are so much easier to clean. It is perhaps not quite so easy to produce a good, clean job from the lathe, on account of the intermittent cutting, as may be obtained with the shrouded type; in this case perfectly smooth faces can be produced. It is, however, difficult to clean out the channels in the shrouded disk. These channels are cored out, and in consequence are always somewhat rough.

It is important to notice that, in the case of direct-coupled pumps, the shrouded disk is particularly useful, since end play on the engine or motor shaft does not cause the disk to grind on the casing, as would be the case with the open type. This point is particularly important when electric motors are employed for driving directly, since the armatures are often allowed to float $^1/_4$ in. or so. It is due to the increasing use of electric motors for driving that the shrouded disk is perhaps more commonly used nowadays. The extra weight of metal in the shrouded disk is important from the point of view of cost. In consideration of this, it is to be observed that some pump makers allow large clearances between the shrouded disk and the volute casing, and include this area as part of the cross-sectional area of the volute, thereby saving metal in the volute casting. Hence the extra cost of metal in the disk may be made up by the smaller volute casting, which, in large pumps, may be very considerable. In the opinion of the author, this practice, besides increasing the disk friction, reduces the efficiency of the volute, as the water in these side pockets lags, or probably becomes "dead."

### Proportions of the Eye and Periphery

The remarks which follow apply to all of the ordinary types of centrifugal pumps, only slight modifications being required, which will depend upon the duty of the pump.

In general, the best efficiency will be obtained when the peripheral velocity of the disk is about 0.9 $\sqrt{(2gH_m)}$ for pumps with guide vanes, and radial-exit vane tips. For pumps having plain volutes, the best peripheral speed is about 1.1 $\sqrt{(2gH_m)}$ when the vane-tip angles at exit are about 38 to 40 deg., but may be as high as 1.3 $\sqrt{(2gH_m)}$ when the angles are as small as 15 to 16 deg. The pump is only efficient at the speed and discharge for which it was designed, and since it is only possible to design for one particular speed and discharge, it is important that the pump should always be worked at that speed.

In all cases the eye of the pump must be large enough to

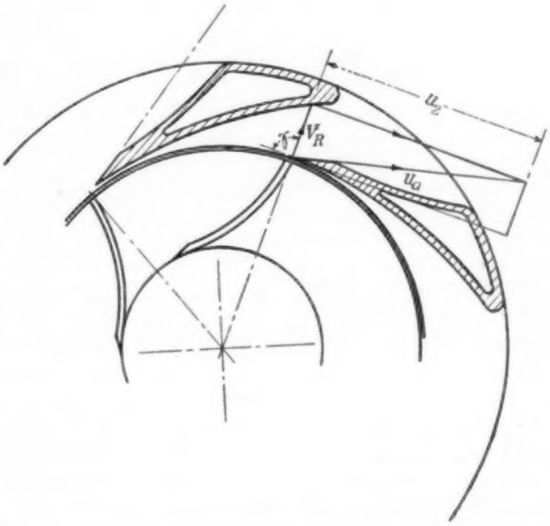


Fig. 6 Velocity Diagram for Turbine Pump Having Radial-Tip Vanes at Discharge and Guide Vane

Suitable Velocities, etc.: $u_2 = 0.9\sqrt{(2gH_T)}$
$V_R = 0.23\sqrt{(2gH_T)}$
$\gamma = 90$ deg.

allow the passage of the whole of the water at a velocity about equal to that in the suction pipe. For general purposes the diameter of the disk can be made about twice that of the eye, due regard being given to the peripheral velocity, as given above. This proportion will be found suitable for moderate speeds.

It often happens that special low speeds are required, and this often necessitates a ratio of the eye to disk as great as 1:5. A pump with which the author has had some experience was used for pumping and circulating water through a condenser, being driven direct by a small low-speed steam engine. The diameter of the eye in this case was $^1/_5$ of the peripheral diameter; approximately. Such proportions do not permit high working efficiencies to be obtained, on account of excessive disk friction: this point is, however, considered of secondary importance in these special cases.

Conversely, when high speeds of rotation are required, the diameter of the periphery may be only $1^1/_2$ times the diameter of the eye.

The deciding factor is the best peripheral speed, as given above, and therefore, with this point in view and the quantity of water to be dealt with, the disk can be proportioned. In the case of the open disk no appreciable axial movement must be allowed, while with a shrouded disk about $^1/_4$ in. on either side of the center may be allowed; this may be greater in large pumps.

### Vanes

The requisite number of vanes will depend upon the speed of the disk. For general purposes, 8 to 12 vanes will suffice, but where high speeds are to be used, 12 to 24 vanes may be necessary in order to avoid excessive slip. The whole question depends upon speed, but the majority of moderate-speed pumps have either 8 or 12 vanes; if too many are provided, the waterways become too small. The vanes should be made as thin as is conveniently possible to cast, while the same applies to the shrouding, if such is used: about $^3/_8$ in. to $^1/_2$ in. is suitable for the vanes in most cases of moderate-sized pumps, while the shrouding should not be much more than $^1/_4$ in.

### Width of Waterways

The best velocity of flow through the disk is about 0.25 $\sqrt{(2gH_m)}$, or approximately one fourth of the peripheral speed, but often lower speeds will be found practicable, particularly in the high-head single-stage pumps. To keep the speed constant, the sides of the disk should be of hyperboloidal form. This is obtained by making the product of the width of the waterway at any radius and that radius a constant quantity. In some cases the velocity of flow through the disk is not constant, the speed at exit being reduced slightly. The effect of such changes will be apparent on reference to the velocity diagram, Fig. 1, and it is a matter of individual experience as to which gives the best results. In all cases the values selected should be within the limits given. When calculating the widths of waterways, the thickness of the vanes must be taken into account.

### Vane-Tip Angles

For low lifts, say, 25 to 60 ft., an exit angle of 38 to 40 deg. is suitable, while an entry angle of 18 to 24 deg. holds for the same conditions. For lower lifts the exit angle needs reducing somewhat, the same entry angles being suitable.

In most high-lift turbine pumps, the exit vane tips are radial.

The effect of altering the exit angle will be apparent from equation $V_W = u_2 - V_R \cot \gamma$. The cotangent of an angle reduces as the angle increases, and therefore $V_W$ becomes greater as $\gamma$ is increased, and becomes nearer to $u_2$. The loss due to the impact of the water leaving the disk and meeting that flowing in the volute may therefore be exceptionally high. The manometric efficiency will also be affected.

When the angle is reduced it becomes necessary for the disk to run faster in order to pump against a given head. The result of this will be to increase disk friction, and also mechanical friction in the bearings.

For the water to enter the vanes without shock, it will be observed by referring to the velocity diagram, Fig. 1, that $\tan^{-1}(V_R/u_1) = \alpha$.

### Stresses in the Disk

The stresses in the disk are not easy to calculate; the principal stresses involved are the circumferential and the radial. The radial will be maximum at the hub, and the circumferential at the periphery. In order to reduce friction, the disk is often cut away toward the periphery. This should be done with care, and consistent with the stresses involved. (See Morley's Strength of Materials.)

The hub of the disk is important and should be made so as to provide good bearing length for the shaft. The disk should be pressed on tightly over a key, the usual drive-fit allowance being permitted.

### Bearings and Glands

The bearings of a centrifugal pump should always be of ample length; from $2^1/_2$ to $3^1/_2$ times the shaft diameter is usual. The question of having ample bearing area is important in high-speed pumps, particularly since, if too small, excessive wear will occur and the shaft will, of course, drop. This may result in the impeller's fouling the casing, especially if the clearances are slight. The ring-oiler bearing is the usual type employed, although plain solid bushes are often put in, particularly where a cheap job is desired. In all high-speed work the ring-oiler bearing is to be recommended; the solid bush bearing is, however, more convenient in the smaller pumps. With this latter type, lubrication is often effected by means of grease cups and screwed caps.

The glands necessary to prevent excessive leakage should always be bored with a slight clearance, the usual allowance being 0.015 in. The length of the stuffing boxes should be about equal to the shaft diameter, suitable neck rings also being provided.

The best packing for pump stuffing boxes is undoubtedly rawhide. With this material the shaft suffers no scoring, and rings can easily be replaced or added to the stuffing box. Square-section flax, graphited and greased, is often used, but often to the detriment of the shaft.

### Priming Apparatus

An important point to consider in the design of the pump is the position in which it is to work. Before pumping will commence, the pump and suction pipes must be full of the liquid to be pumped. This necessitates its either being "drowned," or some means provided to exhaust the air and vapor. It is not always possible or desirable to work a pump "drowned," and, generally speaking, some auxiliary apparatus must be provided to prime the pump.

There are three methods in general use, which may be denominated as follows:

*a* Steam ejectors
*b* Vacuum pump, and
*c* Foot valve and filler.

In some cases automatic contrivances are employed.

Method *b* is usually most convenient, and in small installations a hand pump will suffice, while method *c* is also suitable for small plants. These two methods are often employed unless the pump happens to be located near or within easy reach of a steam supply. In such cases the first method would perhaps be desirable.

Small oil pumps, and circulating pumps for cooling water in internal-combustion-engine work, are usually located in such a position that they always remain full, or in some cases are completely "drowned."

The foot valve and filler method, although convenient in many ways, is often very unsatisfactory, particularly so if gritty or sandy material is to be pumped. Small particles get underneath the valves and leakage takes place, with the result that the filling of the pump becomes difficult, if not impossible. If such valves are used, a screen must always be provided to prevent, as much as possible, the occurrence of the trouble mentioned.

### Valves

Immediately next to the pump, and on the delivery side, a sluice or check valve must always be provided. This becomes necessary to prevent water rushing down the delivery pipe during priming, and either smashing the impeller or bursting the pump.

Sluice valves with wheel and screw can be hand operated when the size does not exceed 20 in. Larger sizes require

gearing, while in exceptional cases hydraulic or other power may be required.

### Materials of Construction

For such purposes as the pumping of water and oil, cast iron is usually employed for the casings of centrifugal pumps, a good-quality, close-grained material giving excellent results. For such purposes as dredging, or the pumping of gritty water, and in fact in all cases where solid material passes through the pump, special precautions are necessary. The wear on the casing, and also on the impeller, in such cases is very severe, and cast steel may be required. The cost of such is great, and generally special linings of manganese steel are inserted, or, as in some cases, chilled castings are employed.

Small pumps are often made entirely of bronze or a cheap gun metal.

For such purposes as the pumping of acids, again special material must be used. In such cases, an acid-resisting material must be used, there being several alloys on the market which more or less fulfil the condition.

The disks of pumps are often made of good-quality, close-grained cast iron, and are painted and varnished after being machined. Some manufacturers, however, use good-quality bronze for their disks and machine them all over; painting in this case is not necessary.

In the special cases mentioned, cast steel is very often used, since hard wear is obtained with this material, which is of course essential where solid matter has to be dealt with.

For the shaft, mild steel is suitable, having an ultimate tensile strength of 28 to 30 tons. The stress carried by the shaft is not usually severe, the loading being fairly constant. In the case of high-speed pumps the shaft should run in gun-metal brasses provided with white-metal pockets or white-metal linings. Solid gun-metal bushes are suitable for small and lower-speed pumps. To prevent corrosion of shafts, brass protecting sleeves are fitted.

## Discussion

I. E. Moultrop.[4] Many valuable data of interest to pump designers have been presented in the three papers on centrifugal pumps.[5] I should think that these studies should help the pump designers to determine the characteristics of pumps at all capacities before they are built.

I should like to say a word in reference to centrifugal pumps from the standpoint of the purchaser and operator of such pumps.

During the past few years more attention has been paid to testing the pumps after installation than heretofore. This is proper because the size of the pumps has been increasing by leaps and bounds, and the kilowatt-hours consumed by the motors that drive the pumps have become a matter of major importance to the users of centrifugal pumps.

These tests have developed the fact that the pumps in operation in many cases have decidedly different characteristics from those expected. In many cases they fail to meet the guaranteed head, capacity, and efficiency, and even more often fail to show the expected characteristic curves from zero to full capacity.

The pump designers should realize that it is no longer satisfactory for a centrifugal pump to meet its guarantees at one particular capacity. What the purchaser needs are the complete characteristic curves, and the manufacturer should bend every effort to bring about the time when he can guarantee that the pump will perform in accordance with the characteristic curves at all capacities.

We now have installed boiler-feed pumps requiring approximately 2600 hp. to drive them. Before such pumps are installed the controllers must be designed. It is impossible to properly design the controllers unless the characteristics of the pumps are known.

We are not "out of the woods" in the case of any of the major pumps in a steam-electric generating station.

From the standpoint of the purchaser and operator of centrifugal pumps I would urge the pump manufacturers to intensively study the problem so that they can guarantee the pumps at all capacities within reasonable limits. Larger and larger pumps are being needed to keep step with the continually increasing size of turbine and boiler units. I realize that the pump manufacturers have a big problem, but it is up to them to solve it. The users of their pumps are willing to help as much as possible.

[4] Chief Engineer, The Edison Electric Illuminating Co., Boston, Mass. Mem. A.S.M.E.

[5] This discussion applies also to the papers by M. D. Aisenstein and Joseph Lichtenstein on the same subject. See papers HYD-50-1 and -2.

W. M. White.[6] The paper is inaccurate, in that the impeller in Fig. 6 should be turned in the opposite direction. Otherwise it cannot direct the water into the channels provided. The author further says that centrifugal pumps having guide vanes in the discharge are the most efficient type. The writer cannot agree with this statement. In the light of modern American practice it is not correct.

The Author. The author thanks Mr. Moultrop for his opening remarks. With regard to the difficulties of pump users or prospective ones, the author has no doubt that these problems are being faced by pump manufacturers seriously and that more and more information is becoming available almost daily.

In reply to Mr. White's first remark, the author regrets that due to oversight the impeller portion of the drawing was allowed to go forward badly drawn. The direction of motion of the impeller is intended to be clockwise, and the vane tips radial at exit. In regard to the second point raised, some misunderstanding surely prevails. If, say, for a head of 250 ft. a guide-vane pump is provided and the quantity of water to be handled is fairly small, then it will give a higher efficiency than a volute pump in the same service. In all cases where a high velocity of discharge from the disk occurs and when the head is great, some means must be provided to convert a maximum of the kinetic energy of the water at discharge from the disk pressure energy. Guide vanes are common for this purpose, and in addition in multi-stage pumps they provide a guide from the outlet of one wheel to the eye of the next. The statement referred to was intended to apply to turbine pumps dealing with high heads and running at high speed. These machines, when carefully designed, undoubtedly give very high efficiency.

[6] Chief Engineer, Allis-Chalmers Mfg. Co., Milwaukee, Wis. Mem. A.S.M.E.

HYD-50-5

# Computation of the Tail-Water Depth of the Hydraulic Jump in Sloping Flumes

BY ROBERT W. ELLMS,[1] CLEVELAND, OHIO

*This investigation deals primarily with the methods of computing the tail-water depth of the hydraulic jump when it is produced in sloping flumes. The author has developed two formulas for this calculation based upon the unpublished work of A. G. Levy and J. W. Ellms of the Cleveland Water Department, and of J. R. Fleming and the author in a thesis presented to Case School of Applied Science. In this paper are given a description and the data of the latter's thesis work, and certain data obtained by the two former investigators. From a study of the results of these experiments the author has drawn certain conclusions as to what takes place in the hydraulic jump when it is produced in sloping flumes, and attempts an explanation of this spectacular and baffling phenomenon.*

The hydraulic jump is generally described as the turbulent passage of water from a high velocity and low depth to a much greater depth and with a corresponding decrease in velocity. The jump may occur under suitable conditions in nature, such as on the shores of the ocean, or of large lakes, or in streams, and may be artificially produced at the foot of dams and in specially constructed flumes. Probably the first recorded studies of this phenomenon were made by Bidone in 1819, and published in the Transactions of the Royal Societies of Turin. Later investigators include Gibson, Ferriday, Lane, Kennison, Hines, Riegel, Beebe, and Levy and Ellms. The four latter investigators, R. M. Riegel and J. C. Beebe of the Miami Conservancy District, and A. G. Levy and J. W. Ellms of the Cleveland Water Department, experimented with sloping and expanding flumes, while all the previous investigators used practically level flumes of constant cross-sectional area.

The experiments conducted by the Miami Conservancy District were to determine what type of flume construction would insure the occurrence of the hydraulic jump in the flood run-off water leaving large retarding basins placed beside the Miami River. The excess kinetic energy in the water was to be dissipated in the hydraulic jump, which was produced just below restricted dam outlets. J. W. Ellms of the Cleveland Water Department conceived the idea of using the turbulent action of the jump for the mixing of chemical solutions with the water to be treated in water-purification processes, and with A. G. Levy he conducted experiments in 1920 with a large experimental flume. Their object was to design a flume which would properly control the jump with the expenditure of a minimum amount of energy, while still maintaining a satisfactory mixing action. In this process it became very important to accurately compute the surface curve of the water both before and after the jump, in order to determine the minimum loss of head under which the jump could operate. The surface curve up-stream from the point of jump was readily computed by the application of Bernoulli's theorem, but it was the failure of the classical momentum formula to give the correct depth of tail water when applied to a jump produced in a sloping flume that led to the investigation of several slopes by J. R. Fleming and the author in May, 1927. The object of this investigation was to discover a possible relation between the slope of a flume in which the hydraulic jump was being produced, and the depth of tail water. The results of this work appeared to be so satisfactory as to warrant the belief that they would be of general interest to hydraulic engineers.

## Description of Experimental Apparatus

The work conducted by J. R. Fleming and the author was carried out at the Baldwin Filtration Plant in Cleveland, Ohio. The supply of water was taken from a high-pressure main, controlled by a four-inch valve, passed through a water meter, and then into a large wooden head tank, and into which the throat of the flume was built. The expanding wooden flume was made of $^3/_4$-in. matched lumber, and had a maximum capacity of 1.5 c.f.s. (cu. ft. per sec.). It was attached to the protruding end of the throat as shown in Fig. 1, and so constructed as to make a flexible joint at $A$, which enabled the slope to be varied from 0.15 ft. per ft. to 0.30 ft. per ft. Weir boards and an adjustable gate, controlled by a hand screw, were located at the down-stream end of the flume for the purpose of controlling the tail-water depth. A wooden chute was placed at the discharge end of the flume to receive the water and carry it to the sewer. The detailed dimensions of the flume are shown in the plan and elevation drawings of Fig. 1.

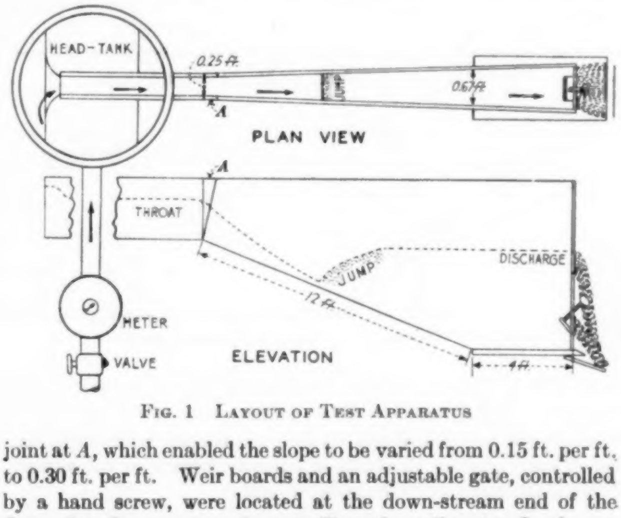


FIG. 1 LAYOUT OF TEST APPARATUS

## Method of Procedure

The slope of the flume was first established with the aid of a level and leveling rod, and then a reference line, obtained by filling the flume with water, was drawn on an inside wall. The elevation of this reference line from station No. 7 was determined and all tail-water depth measurements were referred to it. Station No. 1 was located at the throat. On the bottom of the flume, heavy black lines were drawn at right angles to the line of flow, and spaced at two-foot intervals, marking the positions of stations Nos. 2, 3, 4, 5, 6, and 7, respectively. The quantity and rate of flow of the water were measured by an accurately calibrated water meter and stop watch. The depth of tail water was regulated by the addition or removal of weir boards at the discharge end of the flume, and a finer adjustment obtained by a gate which could be operated by a hand screw.

The jump was made to occur at a given station and the tail-water depth was then measured from the reference line by means of a steel scale which was lowered into the flume until it just

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touched the surface of the water. This was done for quantities of 1.0 c.f.s. and 1.5 c.f.s., and with slopes of 0.22 and 0.30 ft. per ft., and with the jump taking place at the stations and mid-stations listed above.

### Hydraulic-Jump Computations

The water issuing from the head tank and passing into the throat drops to the critical depth, the value of which may be determined by the formula

$$d_c = \sqrt[3]{\frac{Q^2}{gb^2}}$$

in which $d_c$ = critical depth in ft.
$Q$ = quantity in c.f.s.
$b$ = width of throat in ft.
$g$ = acceleration due to gravity.

The surface curve down the slope may be calculated by equating the change of energy from one station to the next to the


Fig. 2 Hydraulic Jump in Horizontal Flume

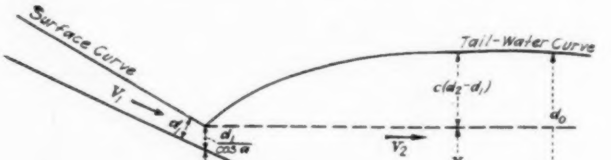


Fig. 3 Hydraulic Jump in Sloping Flume

head lost in friction between stations, as stated by the Chézy formula. This involves a rather tedious cut-and-try process to solve for the new depth and velocity at each succeeding station; but when carefully executed, accurately computes the surface curve of the water up to the point of jump.

When the jump takes place in a horizontal flume, the tail-water depth may be calculated by equating impulse to change of momentum.

In Fig. 2, let $d_1$ = depth of stream entering hydraulic jump
$d_2$ = depth of stream following hydraulic jump
$V_1$ = velocity of stream entering hydraulic jump
$V_2$ = velocity of stream following hydraulic jump.

The change of momentum equals $(wQ/g)(V_1 - V_2)$, and the impulse producing this change of momentum equals $\frac{w}{2}(d_2^2 - d_1^2)$, in which $Q$ is the quantity in cubic feet per second per unit width of stream, and $w$ equals the unit weight of water flowing. Equating impulse to change of momentum and solving for $d_2$ gives

$$d_2 = \sqrt{\frac{2V_1^2 d_1}{g} + \frac{d_1^2}{4}} - \frac{d_1}{2} \quad \text{[1]}$$

This formula gives a value for the depth of tail water which is much too great when the jump is made to take place in a sloping flume, and plainly shows the need for a special formula. New derivations of Equation [1] were sought, using the change-of-momentum principle as applied to a sloping flume, and in every case an indeterminate equation resulted. After numerous attempts to discover a correct combination of the velocity, the elevation of the station before the jump, and the depth of water before and after the jump, which would have some definite and constant relation to the slope, it was finally observed that

$$\frac{d_0 - z - \dfrac{d_1}{\cos a}}{d_2 - d_1} = f(\sin a) \quad \text{[2]}$$

In the above Equation [2] and Fig. 3, let

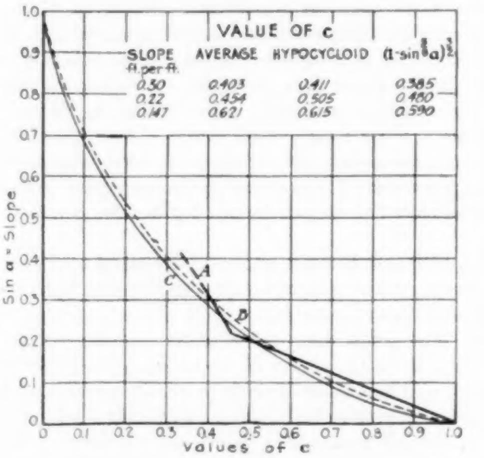


Fig. 4 Plotting of $f$ (sin $a$) for Equation [2]

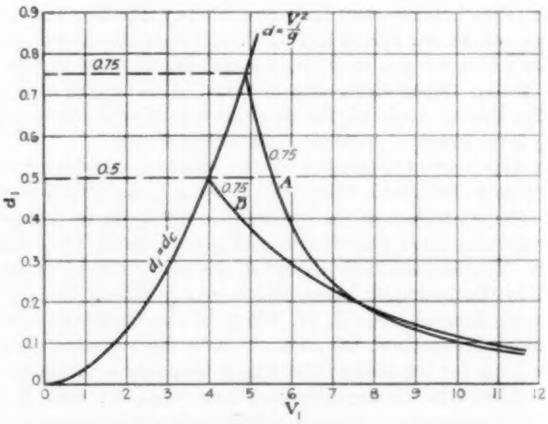


Fig. 5 Corrected Momentum Formula for Sloping Flume
Curve A = $d_2$ according to the momentum formula.
Curve B = $d'_2$ in sloping flume referred to a horizontal condition.

$d_0$ = observed depth of tail water
$d_1$ = depth of water measured normal to the bottom of the flume before the jump
$d_2$ = depth of tail water as calculated by Equation [1] for the same $V_1$ and $d_1$
$a$ = angle which the flume makes with the horizontal
$z$ = elevation of the station at which the jump takes place
$Y_1 = z + \dfrac{d_1}{\cos a}$
$j$ = $d_2 - d_1$ and $c(d_2 - d_1) = cj$, where $c$ equals the constant sought.

After plotting sin $a$ against $c$ it was noted that a curve through these points followed the general form of a modified hypocycloid of four cusps, the equation of which is $x^{2/3} + y^{2/3} = k^{2/3}$. Substituting $k = 1$, $x = c$, and $y = \sin a$ gives

$$c^{2/3} + (\sin a)^{5/3} = 1^{2/3}$$
$$c^{2/3} = 1 - (\sin a)^{5/3}$$
$$c = [1 - (\sin a)^{5/3}]^{3/2}$$

The final tail-water depth equation may be derived by substituting the value of $c$ for $f$ ($\sin a$) in Equation [2].

$$\text{Thus } \frac{d_0 - z - \dfrac{d_1}{\cos a}}{d_2 - d_1} = [1 - (\sin a^{5/3})]^{3/2}, \text{ and}$$

$$d_0 = [1 - (\sin a)^{5/3}]^{3/2} (d_2 - d_1) + \frac{d_1}{\cos a} + z, \text{ or}$$

the complete equation for $d_0$ in terms of $d_1$, $V_1$, $z$, and the angle $a$ of the flume becomes

$$d_0 = [1 - (\sin a)^{5/3}]^{3/2} \times \left[\sqrt{\frac{2d_1V_1^2}{g} + \frac{d_1^2}{4}} - \frac{3}{2} d_1\right] + \frac{d_1}{\cos a} + z \ldots [3]$$

The calculated tail-water depths given by Equation [3] are listed in Tables 1 and 2 in the next column.

Column $D$ of these tables shows the computed values of $f$ ($\sin a$) in Equation [2], as determined from the observed data. Curve $A$ of Fig. 4 shows the plotting of the average value of $f$ ($\sin a$) for each of the three slopes. Curve $B$ is the curve of the pure hypocycloid, while Curve $C$ is that of the modified hypocycloid. The reason for changing the exponent of $\sin a$ from $^2/_3$ to $^5/_3$ was to bend the curve down lower and thus make it pass through the more likely average of the observed data plottings.

While the depth of tail water as computed by Equation [3] is in excellent agreement with the observed depth for the large majority of cases, there is a marked deviation in the calculated depth of tail water by this formula when the values of $d_1$ and $V_1$ are near the critical depth and critical velocity. In some unpublished data of Levy and Ellms, given in Table 2, the $d_0$ as computed by Equation [3] gives values that are much too low when the jump is made to take place near the throat, or when the water is flowing near its critical depth and critical velocity. This tendency may be observed for the three rates of flow with which they experimented. The value of $c$ exceeds unity in at least two cases, which means that the water actually jumped higher on the slope than the impulse formula alone would give for a flume in the horizontal position. It seemed that the error lay in the use of the momentum formula [1] in the derivation of Equation [3]. That is, a new formula for $d_2$ which would give a better agreement with $d_0$ in formula [3], when the water was flowing just below the critical depth, was looked for as a substitute for the classical momentum formula. This analytical study of the data and formulas was carried on after the presentation of the thesis.

When water is flowing at its critical depth and critical velocity in a horizontal flume of constant width, an increase in depth would mean an increase in energy. If the water is flowing at its critical depth into a sloping flume and an increase in section is produced, such that the final depth approaches infinity and the velocity approaches zero, the entire surface curve may be accurately computed by the application of Bernoulli's theorem. In this case, for all practical purposes, the increase in depth measured from the point at which the change of section takes place, is equal to $^3/_2\, d_c$. On this assumption, the depth of water after the jump

TABLE 1 OBSERVED AND COMPUTED TAIL-WATER DEPTHS

| Station | $Y_1$ | $d_1$ | $V_1$ | $d_0$ (Eq. 3) $A$ | $d_0$ (Eq. 8) $B$ | $d_0$ Observed $C$ | $c$ (Eq. 3) $D$ | $K$ (Eq. 8) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Slope 0.30 ft. per ft.; $Q$ = 1.5 c.f.s. | | | | | |
| 2 | 3.468 | 0.468 | 10.00 | 3.861 | 3.917 | 3.910 | 0.435 | 0.0354 | Equation [10] gives almost identical values for $d_0$ as listed in column $B$ |
| 3 | 2.740 | 0.340 | 11.31 | 3.186 | 3.202 | 3.110 | 0.319 | 0.0276 | |
| 4 | 2.067 | 0.267 | 12.21 | 2.504 | 2.527 | 2.500 | 0.365 | 0.0337 | |
| 5 | 1.419 | 0.219 | 12.92 | 1.874 | 1.869 | 1.871 | 0.367 | 0.0364 | |
| 6 | 0.790 | 0.190 | 13.16 | 1.236 | 1.221 | 1.294 | 0.436 | 0.0430 | |
| | | | | | | | 0.397 | 0.0352 | Averages |
| | | | | Slope 0.30 ft. per ft.; $Q$ = 1.0 c.f.s. | | | | | |
| 2 | 3.355 | 0.355 | 9.23 | 3.671 | 3.722 | 3.745 | 0.497 | 0.0389 | |
| 3 | 2.650 | 0.250 | 10.75 | 3.012 | 3.034 | 2.824 | 0.185* | 0.0134* | Observed $d_0$ in error |
| 4 | 1.987 | 0.187 | 11.62 | 2.350 | 2.359 | 2.395 | 0.414 | 0.0400 | |
| 5 | 1.358 | 0.158 | 11.94 | 1.716 | 1.724 | 1.765 | 0.437 | 0.0460 | |
| 6 | 0.738 | 0.138 | 12.08 | 1.090 | 1.078 | 1.030 | 0.391 | 0.0306 | |
| | | | | | | | 0.409 | 0.0389 | Averages |
| | | | | Slope 0.22 ft. per ft.; $Q$ = 1.5 c.f.s. | | | | | |
| 3 | 2.128 | 0.368 | 10.45 | 2.638 | 2.671 | 2.631 | 0.473 | 0.0337 | All observed values are slightly low |
| $3^1/_2$ | 1.865 | 0.325 | 10.85 | 2.388 | 2.399 | 2.348 | 0.443 | 0.0323 | |
| 4 | 1.612 | 0.292 | 11.17 | 2.139 | 2.139 | 2.095 | 0.441 | 0.0326 | |
| $4^1/_2$ | 1.364 | 0.264 | 11.48 | 1.885 | 1.888 | 1.825 | 0.424 | 0.0314 | |
| 5 | 1.122 | 0.242 | 11.69 | 1.632 | 1.636 | 1.570 | 0.423 | 0.0309 | |
| $5^1/_2$ | 0.883 | 0.223 | 11.89 | 1.389 | 1.392 | 1.215 | 0.314 | 0.0222 | |
| | | | | | | | 0.441 | 0.0322 | Averages |
| | | | | Slope 0.22 ft. per ft.; $Q$ = 1.0 c.f.s. | | | | | |
| 3 | 2.025 | 0.265 | 9.68 | 2.432 | 2.452 | 2.395 | 0.438 | 0.0307 | Equation [10] gives almost identical values for $d_0$ as listed in column $B$ |
| $3^1/_2$ | 1.774 | 0.234 | 10.01 | 2.190 | 2.205 | 2.200 | 0.492 | 0.0361 | |
| 4 | 1.530 | 0.210 | 10.35 | 1.944 | 1.942 | 1.930 | 0.465 | 0.0341 | |
| $4^1/_2$ | 1.292 | 0.192 | 10.53 | 1.705 | 1.707 | 1.663 | 0.433 | 0.0313 | |
| 5 | 1.056 | 0.176 | 10.71 | 1.456 | 1.462 | 1.456 | 0.478 | 0.0351 | |
| $5^1/_2$ | 0.824 | 0.164 | 10.84 | 1.230 | 1.224 | 1.235 | 0.486 | 0.0372 | |
| | | | | | | | 0.466 | 0.0341 | Averages |

* These values omitted from averages.

TABLE 2 OBSERVED AND COMPUTED TAIL-WATER DEPTHS

Slope 0.147 ft. per ft.

| $Q$ c.f.s. | $Y_1$ | $d_1$ | $V_1$ | $d_0$ (Eq. 3) $A$ | $d_0$ (Eq. 8) $B$ | $d_0$ Observed $C$ | $c$ (Eq. 3) $D$ | $K$ (Eq. 8) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| 20 | 3.67 | 0.21 | 11.63 | 4.272 | 4.257 | 4.37 | 0.686 | 0.0440 | |
| | 4.01 | 0.22 | 11.86 | 4.635 | 4.621 | 4.67 | 0.622 | 0.0394 | |
| | 4.36 | 0.24 | 11.41 | 4.974 | 4.967 | 4.98 | 0.595 | 0.0368 | |
| | 4.69 | 0.26 | 11.17 | 5.304 | 5.303 | 5.32 | 0.605 | 0.0375 | |
| | 5.04 | 0.27 | 11.51 | 5.684 | 5.683 | 5.63 | 0.541 | 0.0325 | |
| | 5.39 | 0.36 | 9.54 | 5.922 | 5.965 | 5.98 | 0.656 | 0.0376 | |
| | 5.91 | 0.43 | 8.57 | 6.364 | 6.443 | 6.42 | 0.766* | 0.0412 | |
| | | | | | | | 0.618 | 0.0384 | Averages |
| 31 | 3.83 | 0.28 | 13.46 | 4.633 | 4.615 | 4.71 | 0.610 | 0.0443 | Equation [10] gives almost identical values for $d_0$ as listed in column $B$ |
| | 4.09 | 0.30 | 13.06 | 4.881 | 4.871 | 4.93 | 0.626 | 0.0400 | |
| | 4.38 | 0.32 | 12.98 | 5.183 | 5.274 | 5.21 | 0.610 | 0.0432 | |
| | 4.75 | 0.38 | 11.77 | 5.488 | 5.511 | 5.56 | 0.648 | 0.0388 | |
| | 5.17 | 0.40 | 12.09 | 5.949 | 5.969 | 5.87 | 0.530 | 0.0308 | |
| | 5.44 | 0.49 | 10.35 | 6.080 | 6.154 | 6.15 | 0.652 | 0.0350 | |
| | 6.04 | 0.64 | 8.91 | 6.554 | 6.676 | 6.66 | 0.715* | 0.0354 | |
| | 6.36 | 0.81 | 7.39 | 6.649 | 6.867 | 6.96 | 1.230* | 0.0486 | |
| | | | | | | | 0.613 | 0.0389 | Averages |
| 42 | 4.14 | 0.37 | 14.53 | 5.115 | 5.108 | 5.14 | 0.606 | 0.0385 | |
| | 4.23 | 0.37 | 14.59 | 5.210 | 5.200 | 5.29 | 0.638 | 0.0400 | |
| | 4.47 | 0.40 | 14.10 | 5.432 | 5.428 | 5.50 | 0.633 | 0.0384 | |
| | 4.86 | 0.49 | 12.21 | 5.692 | 5.739 | 5.78 | 0.652 | 0.0383 | |
| | 5.09 | 0.47 | 13.32 | 6.028 | 6.049 | 6.01 | 0.578 | 0.0345 | |
| | 5.39 | 0.57 | 11.70 | 6.193 | 6.271 | 6.33 | 0.692 | 0.0392 | |
| | 6.20 | 0.80 | 9.57 | 6.732 | 6.951 | 6.86 | 0.734* | 0.0295 | |
| | 6.58 | 1.03 | 7.79 | 6.881 | 7.141 | 7.18 | 1.180* | 0.0395 | |
| | | | | | | | 0.633 | 0.0374 | Averages |

Above data from unpublished work of Levy and Ellms computed by Equations [3] and [8].

* These values omitted from averages.

or change of section, referred to the horizontal case, was drawn as shown by Curve $B$ of Fig. 5. The problem was to determine the equation of Curve $B$.

Assuming $d_1 = d_c$, then $d'_2 = {^3/_2}\, d_c$ or $^3/_2 d_1$, as noted in Fig. 5. If the velocity was increased while $d_1$ remained constant, it was observed that $d'_2 - {^3/_2}\, d_1$ increased directly in proportion to the change of velocity.

Thus

$$\frac{\left(d'_2 - \frac{3}{2}d_1\right)}{V_1 - V_c} = f(d_1) \quad \ldots\ldots\ldots\ldots\ldots\ldots [4]$$

Letting $V_c = \sqrt{gd_1}$, and solving for $d'_2$ gives

$$d'_2 = \frac{3}{2}d_1 + f(d_1)(V_1 - \sqrt{gd_1}) \quad \ldots\ldots\ldots\ldots [5]$$

Taking a series of values for $d_1$ and $V_1$, and $d'_2$ as read from a system of curves similar to Curve $B$ of Fig. 5, and plotting a new curve in order to determine the relation between $d_1$ and the value of the function, Curve $A$ of Fig. 6 was drawn. Owing to the difficulty of determining the equation of Curve $A$, the value of the function of $d_1$ was plotted against the critical velocity $V_c$ corresponding to the critical depth. The result of this plotting is Curve $B$ of Fig. 6 which is virtually a straight line, and for which the equation may be readily determined. Thus

$$f(d_1) = K\sqrt{gd_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots [6]$$

in which $K$ equals the slope of Curve $B$.

The final equation of Curve $B$ of Fig. 5 is therefore

$$d'_2 = \frac{3}{2}d_1 + K\sqrt{gd_1}(V_1 - \sqrt{gd_1}) \quad \ldots\ldots\ldots [7]$$

which gives the theoretical height of jump for a sloping flume referred to the horizontal position.

Since the final formula for $d_0$ as given in the form of Equation [3] would have two empirical constants in it, when Equation [7] was substituted for the momentum formula it was thought best to use the pure hypocycloid for $f$ (sin $a$), or $c$, instead of the modified form. This equation may finally be written,

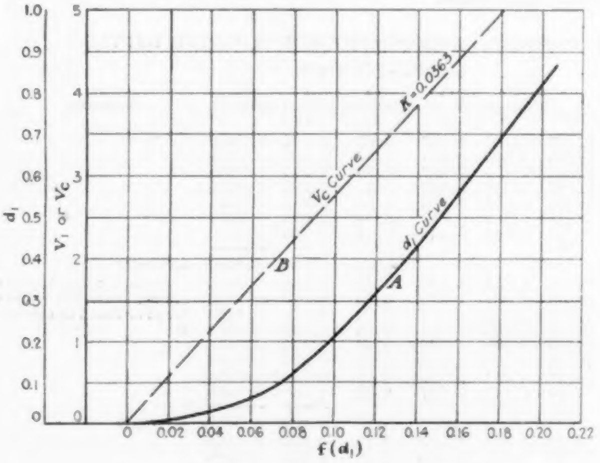


FIG. 6 VALUE OF $f(d_1)$ IN EQUATION [5]

$$d_0 = (1 - \sin^{2/3} a)^{3/2}\left[K\sqrt{gd_1}(V_1 - \sqrt{gd_1}) + \frac{d_1}{2}\right] + \frac{d_1}{\cos a} + z \quad \ldots\ldots [8]$$

From this equation $K$ was computed from all of the available data for each of the three slopes, and the average found to be 0.0363. The depths of tail water as computed by Equation [8] for each case are also listed in Tables 1 and 2 and show a most satisfactory agreement with the observed measurements.

It became apparent that the formula for $d'_2$ was simply $d_2 + \frac{V_2^2 - V_0^2}{2g}$. In other words, an increased cross-section decreases the velocity, with a consequent gain in the static head. This value must be added to the value for $d_2$ as calculated by the momentum formula in order to obtain the true value of $d'_2$ in a sloping and expanding flume. In formula [8], $d'_2 = 0.0363\sqrt{gd_1} \times (V_1 - \sqrt{gd_1}) + {}^3/_2\, d_1$, the value 0.0363 is the average for the two flumes in which experiments were made, and for the quantities of water used in each. The form $d_2 + \frac{V_2^2 - V_0^2}{2g}$ is not dependent on observational data, since it has *no empirical constants*. The value of $V_0$ is always very small and may usually be neglected. When in doubt as to its value, the formula should be solved by the cut-and-try method. $V_2$ equals $\frac{d_1V_1}{d_2}$.

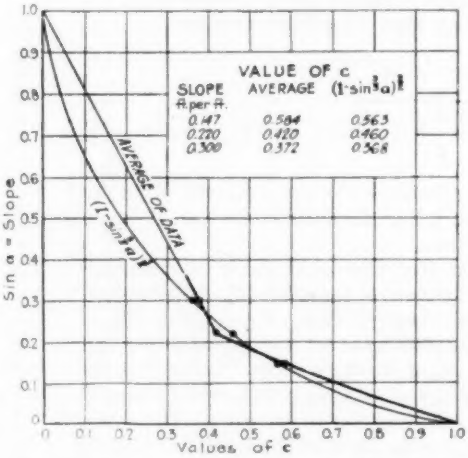


FIG. 7 PLOTTING OF $f$ (SIN $a$) AND $c$ FOR EQUATION [9]

Putting the new value for $d_2'$ in formula [8] gives

$$d_0 = \left(d_2 + \frac{V_2^2 - V_0^2}{2g} - d_1\right)c + Y_1 \quad \ldots\ldots\ldots [9]$$

This form of the equation has but one empirical constant for each particular slope. The average value of $c$ was computed from the data for each slope and found to be as follows:

| Slope, ft. per ft. | Value of $c$ |
|---|---|
| 0.147 | 0.584 |
| 0.220 | 0:420 |
| 0.300 | 0.372 |

The exponent ${}^2/_3$ of sin $a$ in the hypocycloid was changed to ${}^3/_4$, and the resulting function gave values of $c$ for each slope which compared favorably with the above averages; thus

| Slope, ft. per ft. | $(1 - \sin^{3/4} a)^{3/2}$ |
|---|---|
| 0.147 | 0.563 |
| 0.220 | 0.460 |
| 0.300 | 0.368 |

Fig. 7 shows the average curve and the second modification of the hypocycloid. The third general formula for the computation of the tail-water depth for the hydraulic jump, when produced in sloping and expanding flumes, may then be written as follows:

$$d_0 = \left[\sqrt{\frac{2V_1^2d_1}{g} + \frac{d_1^2}{4}} - \frac{3d_1}{2} + \frac{\left(\frac{d_1V_1}{d_2}\right)^2 - V_0^2}{2g}\right] \times (1 - \sin^{3/4} a)^{3/2} + \frac{d_1}{\cos a} + z \quad \ldots [10]$$

Accordingly, all runs were computed using this formula and the results checked almost exactly in every case with those as computed by Equation [8]. For this reason, it was not thought necessary to repeat the tables.

### Discussion and Conclusions

The problem involved was to find a combination of the depth and velocity of water before the jump, and the slope of the flume, and their relation to the tail-water depth. Many combinations

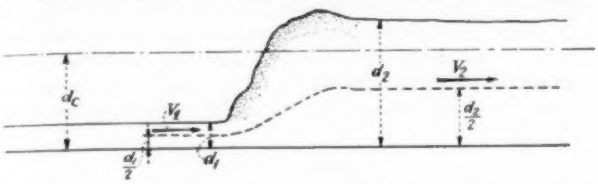


Fig. 8 Hydraulic Jump in Horizontal Flume Showing Rise in Center of Mass

were tried, such as $\frac{d_0 - z - d_1}{d_2} = f(\sin a)$, or $\frac{d_0 - z}{d_2 - d_1} = f(\sin a)$, or simply $\frac{d_0 - z}{d_2} = f$ (sin $a$), and all proved unsatisfactory, the reason being that the ratio $d_2/d_1 = J$ had to be taken into account. The formulas finally developed eliminate the effect of $J$ by subtraction. It was observed that a coefficient taking the form $(1 - k \sin a)$ times the $d_2$ for the horizontal condition, plus $Y_1$, also varied with a change of $J$. Fair agreement with observed depths of $d_0$ were obtained with this equation for an average value of $k = 2.22$. However, these results had to be modified too much for extreme values of $J$, and a more constant relation was looked for.

From Curve $A$ of Fig. 4 the relation $\dfrac{d_0 - z - \dfrac{d_1}{\cos a}}{d_2 - d_1}$ was found to be much more constant in its variation with the variable $\sin a$. A rough test for angles greater than 20 deg. indicated that the value of $f$ (sin $a$) approached zero as sin $a$ approached unity. This fact indicated that $c$ had no appreciable value when the angle was 90 deg. The term $d_1/\cos a$ corrects $d_1$ for a sloping flume, and it can be readily seen that for small values of $a$, this term is nearly equal to $d_1$. As the angle increases $\cos a$ decreases, approaching zero, with the result that this term becomes infinite.

Since Equation [3] did not hold strictly for computed tail-water depths when the water was flowing at or slightly below the critical depth, Equations [8] and [10] were developed and found to give a closer agreement with all observed results. For all practical purposes any of the three Equations [3], [8], and [10] may be used, as brought out by a study of columns $A$, $B$, and $C$ in the tables. Equation [8] is much simpler to use because with a fixed slope the formula may be reduced to one of three terms. For example, with a slope of 0.30 ft. per ft. of slope, where the value of $c$ is 0.411, the equation becomes

$$d_0 = 0.411 \left[ 0.0363 \sqrt{gd_1}\,(V_1 - \sqrt{gd_1}) + \frac{d_1}{2} \right] + Y_1$$

which finally reduces to

$$d_0 = 0.0843 V_1 \sqrt{d_1} - 0.273\, d_1 + Y_1$$

Equation [10] should really be solved by the cut-and-try process, because the actual velocity of the tail water is dependent on the depth $d_0$ and the width of the flume. The term $\frac{V_2^2 - V_0^2}{2g}$ corrects exactly for the change of section and adapts itself to the particular flume used. Thus formula [10] is complete, since it takes care of the change of momentum by the $d_2$ formula, change of section by the velocity term, change of slope by the modified hypocycloid equation, position in the flume by the $z$ term, and the correction of $d_1$ for the angle of the flume. The loss of head due to friction in turbulent water was considered to be so small that it could be neglected in all the formulas developed.

The only data available for the development of these formulas have been for flumes having slopes of 0.147, 0.22, and 0.30 ft. per ft. of slope, respectively. After more data have been obtained for wider ranges of depth, velocity, and slope, it may result in some modification of these formulas, but it is believed that their general form will hold. Hydraulic measurements in rapidly flowing and turbulent water are necessarily open to observational errors, which are reflected in constants of empirically developed formulas of this type. It is, however, rather gratifying to note that the developed formulas hold with a surprisingly small percentage of error for quantities ranging from 1.0 to 40.0 c.f.s.

The production of the hydraulic jump in sloping flumes has led the author to attempt an analysis of this phenomenon, based partly upon the mathematical deductions presented in this paper and partly upon an observational study of the jump in an experimental flume. The following discussion deals with flumes of constant width only.

The accepted definition of the hydraulic jump is the turbulent passage of water from a depth below the critical depth to an alternate momentum stage above the critical depth. The water dissipates a large part of its kinetic energy in passing from the lower to the alternative or upper stage through the turbulent action produced, and probably through much internal impact. When the jump is produced in a practically horizontal flume, the center of mass of the water is raised as shown by the dotted line in Fig. 8. It is this increase in potential energy that gave to the phenomenon

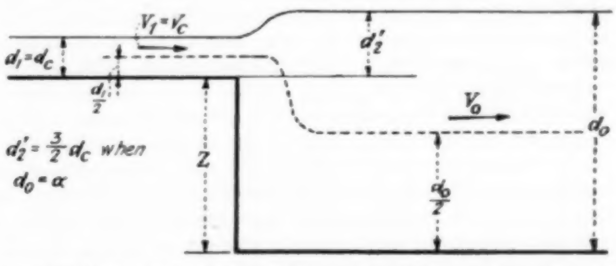


Fig. 9 Effect of Change of Section for Water Flowing at or Above the Critical Depth

the name of the hydraulic jump. The water moving at a high velocity below the critical depth must have the interposition of an outside force upon it in order to make it flow at the greater depth.

An interesting condition arises, however, when the water is made to flow at the critical depth and into a large body of water, as shown in Fig. 9. The rise in the surface of the water is not accompanied by any turbulent action. The center of mass lowers instead of rises, and no jump is produced. The surface curve may be readily computed by the application of Bernoulli's theorem. Formulas [8]. and [10] may be used to compute $d_0$. In this case the depth $d'_2$ is increased simply as a result of the increased section.

If the water flows below the critical depth under conditions similar to those illustrated in Fig. 9, a much more complicated condition arises. When the change of section is such that the velocity of the tail water is greatly reduced, and a jump is produced at this change of section, there exists a combination of the two effects diagrammatically represented by Figs. 8 and 9. Such a combination is shown in Fig. 10 Here the center of mass

lowers and still a "jump" is produced. Mathematical calculations for the value $d'_2$ must be corrected for impact and change of section. Formulas [8] and [10] reduce in the following manner:

$$d_0 = (d'_2 - d_1)(1 - \sin^n a)^{3/2} + \frac{d_1}{\cos a} + z$$

Since $a$ equals zero, $\sin a$ equals zero and $(1 - 0^n)^{3/2} = 1$, and

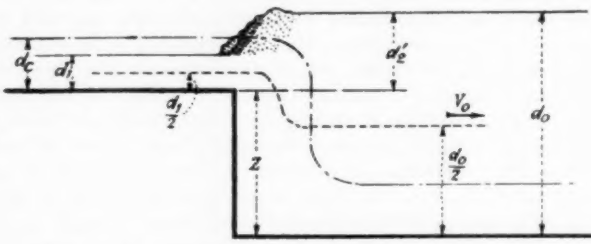

FIG. 10 COMBINATION OF JUMP AND CHANGE OF SECTION

$$d_0 = (d'_2 - d_1)\,1 + \frac{d_1}{1} + z = d'_2 + z$$

Formula [8] gives $d'_2 = 0.0363\sqrt{gd_1}\,(V_1 - \sqrt{gd_1}) + \frac{3}{2}d_1$

Formula [10] gives $d'_2 = d_2 + \frac{V_2^2 - V_0^2}{2g}$

For formula [10] $d_2'$ is found by the cut-and-try method, and friction is neglected. The value $d_2'$ corrects for impact and the velocity term corrects for the change of section. If $z = 0$, $V_0 = V_2$ and $d_2' = d_2$. That is, the conditions are identical with those shown in Fig. 8.

The tail-water depth computation becomes still more complicated when the jump is produced in a sloping flume. Here we have the water before the jump flowing below the critical depth and at some angle $a$ with the horizontal. This angular impact reduces the value of $d_2'$. That is, the value $d_2'$ is less than it would be were the flume in a horizontal position. The exact path of the center of mass in the turbulent portion of the jump is indefinite, because the surface curve from which it is determined is indefinite. These conditions are illustrated in Fig. 11. If $z$ has an appreciable value, the tail-water velocity is reduced, and therefore $d_2'$ will be slightly increased. In the development of the formulas it was found necessary to subtract

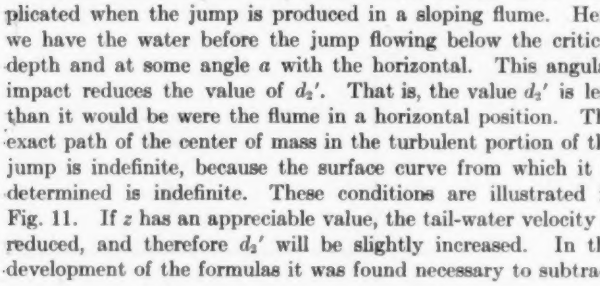


FIG. 11 HYDRAULIC JUMP IN SLOPING FLUME SHOWING PATH OF CENTER OF MASS

$d_1$ from $d_2'$ before multiplying by the hypocycloid term. The values $d_2 - d_1 = j$, and $d_2' - d_1 = j'$, appear more significant than the $d_2$ or $d_2'$ distances, and were used in the development of all three formulas, because they varied so regularly with a change of slope. The modified equation of the hypocycloid corrects the $d_2'$ distance for a sloping flume. Many more data will have to be compiled before it can be said that for any one slope $c$ is *exactly* constant. A slight fluctuation is observed, the magnitude of which is about the same as that due to observational error. Only a slight deviation is observed in the data, and this may be due partly to errors in flume construction or partly to the effect of friction.

In general, formula [10] is complete and has been checked by a wide range of flume conditions and flow conditions. The curve of the modified hypocycloid does not quite fit the data obtained as shown in Fig. 7, but until more slopes are experimented with it is not possible to verify the exact curvature of this line. While work will logically proceed from Equation [10], the author believes that eventually a general equation, void of any empirical constants, may be developed in some such way as the momentum formula was derived, and which will effectually bridge the gap between successive transitional back-water curves where impact is present.

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1 Kennison: "The Hydraulic Jump in Open-Channel Flow at High Velocity;" Trans. A.S.C.E., vol. 80, p. 338.

2 Woodward: "Theory of the Hydraulic Jump and Backwater Curves;" Technical Report of the Miami Conservancy District, Part III.

3 Riegel and Beebe: "The Hydraulic Jump as a Means of Dissipating Energy;" Technical Report of the Miami Conservancy District, Part III.

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# Discussion

A. G. LEVY.[2] The author deserves much credit for the excellent way in which he has analyzed the phenomenon of the jump itself as well as the mathematics involved in the derivation of the several formulas and coefficients entering therein. The paper is a fine contribution to a field of hydraulics in which little has heretofore been accomplished.

In a report[3] by J. W. Ellms and the writer an attempt was made to locate the position of the jump on a sloping, expanding flume, under a definite set of conditions, by the introduction of coefficients varying with the velocities before the jump. These coefficients are of course applicable only to conditions comparable to those under which they were obtained. As limited as this method is, it furnished, so far as the writer knows, the only means for locating the jump on a sloping, expanding flume previous to the derivations of the formulas obtained by the author of this paper. Other engineers who had had occasion to investigate problems of this nature had merely concluded that for a given depth of tail water the jump invariably occurred higher up the slope than the momentum formula indicated. The lack of any method for locating the jump in a sloping flume makes this particular paper all the more valuable.

It seems to the writer that, as the author himself states, his Equation [10] contains all the essential elements entering into a right solution of the problem, with the possible exception of the factor of friction. Inasmuch as friction is acting over a relatively short distance between $d_1$ and $d_0$, during which time the velocity is rapidly being reduced, it is not believed that that particular loss can have very much influence on the value of the coefficients obtained and therefore on the general applicability of the formula. It is of course possible that with very large flows under very high velocities, in which the distance between $d_1$ and $d_0$ increases, friction may play a more important part than is now evident. The author's analysis, however, covers a fairly wide range of quantities, and if this factor were appreciable under conditions

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[3] "Report on Experiments Made with the Hydraulic Jump as a Means by which Chemicals May Be Mixed with Water to Effect Its Purification," by J. W. Ellms and A. G. Levy.

of velocity changes greater than those analyzed, it would seem that it would be more manifest now than it apparently is.

While Equation [10] seems to the writer to be the most complete of the three, it is his opinion that Equation [8] is the most practical. The necessity for a cut-and-try method with the use of Equation [10] in which $d_0$ must be known before $V_0$ can be obtained is apt to arouse considerable mental opposition, particularly as the value of $d_0$ is not known beforehand, even approximately. In the writer's judgment Equation [8] will be the more generally employed, serving at least as a basis for all preliminary studies, with Equation [10] being used only as a final check.

It would be an excellent idea if someone could develop a formula which would "effectually bridge the gap between successive transitional backwater curves where impact is present," provided that such a formula did not become too complicated for practical use. From the possible combinations of elements that might enter such a problem, the writer is not too optimistic of its success and believes that such a formula has its place in the realm of pure mathematics rather than in that of practical hydraulics. Feeling that way, he is all the more appreciative of what has been accomplished and believes that the author has laid the foundation in his Equation [10] wherein all that is necessary is for future experimenters to confirm or modify his coefficients in connection with experimental conditions other than those which the author himself has studied.

L. F. Harza.[4] Without checking over all of the author's paper or the formulas derived, the writer has observed one assumption which is believed to be a fundamental error in the author's hypothesis for deriving his formulas. He has assumed the elevation of the center of mass of the water as a measure of its potential energy. I was taught to consider the surface elevation.

Bernoulli's theorem states that, neglecting losses, the sum of potential and kinetic energy in flowing water remains constant. The energy of any infinitesimal element of flowing water at any point consists of three items, energy of elevation, energy of pressure, and kinetic energy, the two former being in the nature of potential energy. The energy of elevation represented by the elevation of the element above any assumed datum, plus the pressure energy, represented by the depth of the element below the water surface, plus the kinetic energy $V^2/2g$, is constant.

The energy of elevation plus the pressure energy represents the total potential energy and is always equivalent to the elevation of the water surface above the datum. The potential energy is therefore equal to the elevation of the water surface rather than of its center of gravity. Likewise, in any conversion of potential to kinetic energy or vice versa, the change in elevation of the water surface, neglecting losses, should be equivalent to the change in $V^2/2g$.

This principle is so fundamental to all hydraulics that its truth or fallacy should be determined before a discussion of any of the remainder of the paper is in order.

B. F. Groat.[5] I note two points that might be mentioned: In most cases I think we must arrive at the forms of our equations by the indications of mechanics and mathematics, and not by the forms of plottings unless supported by theory, although there may be some exceptions. It is certainly wrong to determine the potential energy of flowing water, where the surface level is maintained by the flow, by reference to the center of gravity of the prism of water, upstream, downstream, or at any section. This has been a common mistake in the past and seems to have had some patronage in the paper.

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[5] Consulting Engineer, Ocean City, N. J.

L. F. Moody.[6] This paper strikes me as being of considerable interest. I think it would make an excellent research subject for graduate students in colleges or some of the hydraulic research laboratories. It involves hydraulic laws applying to flow in general, and it is a subject that can rather easily be handled experimentally with comparatively simple equipment.

One point that I question is the use of the dotted center line, shown in Figs. 3, 8, 9, 10, and 11, marked "path of center of mass." It seems to me that this center-of-mass position is not the significant thing and should not be used for the basis of distinction between the various phenomena, because the position of the center of mass, which is here merely the center of area of the flow, does not determine the potential energy, but only the elevation of the center of the section. The potential energy is determined by this elevation plus the intensity of hydrostatic pressure head at that point, and when you add these two quantities you come out with merely the surface elevation above some fixed datum. I think this point should be made clear.

For example, the author says that "When the jump is produced in a practically horizontal flume, the center of mass of the water is raised as shown by the dotted line in Fig. 8," and a little farther on he says, "The center of mass lowers instead of rises, and no jump is produced."

I think it ought to be made clear there that the center of mass is not the significant thing by itself, but that the position of the water surface above a fixed datum is the significant thing in determining the potential energy.

I also question the expression, "through the turbulent action produced, and probably through much internal impact." To my mind those two things are tied together and are merely two features of the same thing. The turbulent action absorbs and dissipates energy by internal friction and internal impact. So instead of expressing them as two different things, I think they are merely part of the same thing.

One of the points which appealed to me was that the author, as I understand his paper, states that he desired to undertake a rational solution of this problem, but had not fully completed an analysis along purely rational lines, and therefore presents his conclusions as empirical relations, having in mind, I presume, that later he or other workers in this field might tie up these empirical expressions by comparing them with the results derived from a purely rational and mathematical analysis.

I should prefer to have seen a thoroughgoing rational analysis made first before the attempt to derive empirical relations, because after much experience in such problems I have more and more come to the thought that the presentation of results by purely empirical methods is rather dangerous and not conclusive.

For example, in many hydraulic problems we could take the results obtained experimentally and plot them into curves against the particular variables which we believe have the controlling influence, and then derive empirical equations to fit these curves.

Now very often in applying this method you will obtain a series of points, put a smooth curve through them, and then find it is very difficult to say just what the form of equation is that best suits those curves. You might obtain a curve that looks like a parabola, and then apply a parabolic equation. With very little change you might apply a hyperbolic equation or an exponential equation, and usually the accuracy of the experimental data is not sufficient to establish which is the proper contour.

You can often arbitrarily select any number of mathematical equations which give you a curve that will closely fit the one plotted. Therefore for the usual range of experimentation the hydraulic data are not as a rule accurate enough to determine

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the form of the curve. We therefore have to assume some form of curve, whether hyperbolic, exponential, or something else, and fit our equations to it, which will give a rough rule that we can apply with reasonable accuracy.

But that does not go to the root of the problem. That is one reason why I think this subject deserves further study by the author and any others whose interest we can enlist in the matter, to investigate analytically the conditions and to determine a really rational solution. It may come out in close agreement with what the author has derived empirically, and again it may not. It may involve other factors.

I should be hopeful that, if such a rational result may be reached, it can be made broad enough to tie the sloping-flume phenomena with the horizontal-flume phenomena so that the single equation will suit either.

I was interested in Mr. Levy's suggestion that friction will require experimental coefficients of correction. But I agree with him that this is a case where much the larger part of the action is that of turbulence and velocity-head conversion, and the friction will play a relatively minor role, so that a purely rational expression should give us quite a close basis for building up our final formula.

I was anxious to obtain the views of R. D. Johnson, of New York, on the subject, because he has been interested in the hydraulic-jump problem, but Mr. Johnson wrote that the time was so short and the subject so complex that he could not present a formal discussion, and could offer only a few suggestions; and I have his permission to read some of these. He writes:

You are of course perfectly right in pointing out an obvious weakness in Mr. Ellms' paper where he tries to deal with the so-called change in the center of mass as an indication of the change in potential energy. As you say, the significant thing is the change in surface elevation.

To make this point a little more clear, it occurs to me that if you take a tank filled with still water and raise the bottom on one side of the tank to a higher elevation than on the other, you can plot in a curve of the center of mass, but that has no significance. The water is not moving, and it does not even represent potential energy, but only the elevation part of it, since the surface elevation is the thing which determines the potential energy, and that is the same throughout the still-water tank.

Also, if you take the flow over a weir, the center of mass curve would run along at the center of the depth in the approach channel and would rise as the water goes over the crest, but there is not any increase of potential energy; in fact, there is a decrease represented by the drop of the surface curve as the water passes over the crest. So this curve of center of area or center of mass is of no significance there. Mr. Johnson continues:

The most serious defect which I find in this paper is the failure to take into account all of the forces which are acting. Take for example the simple case portrayed in Fig. 10; the free forces there acting are a hydrostatic triangle opposed to the flow equal to

$$d_2^2 \div 2$$

(for unit width of flume and unit weight of fluid) and a hydrostatic triangle favoring the flow equal to

$$(Z + d_1)^2 \div 2$$

The difference between these forces should be equal to the rate at which the momentum changes or

$$\frac{Q}{g}(V_2 - V_0)$$

It looks as though this would result in a cubic equation which would have to be solved by trial, but it would not appear to be very much like the author's solution of this particular case.

I, myself, have no disposition to offer any adverse criticism of this paper without putting in enough time to develop a rational formula for his general case of sloping flumes. . . . The author, at any rate, deserves a lot of credit for having tried to adapt an empirical equation to the phenomenon in question, and I have little doubt that his formula is quite accurate for the range already covered by experiments, but I should never be satisfied to make use of such an empirical equation for conditions very much outside of the range of experiments, as this is always a dangerous thing to do, especially in hydraulic problems.

In a second letter, Mr. Johnson says:

I might call your attention to another matter on page 5, next to the last paragraph, under Fig. 9. The condition which he cites would certainly be most interesting if true. As I read it, the author says that the difference between $d_2'$ and $d_1$ is simply that due to the difference in velocity heads between $V_0$ and $V_c$. I can scarcely think I am reading correctly and I should like to know if that is what you read. This would indeed be most remarkable, because there would then be no turbulence whatever if a stream, say, 10 ft. deep at about 18 ft. velocity, should run abruptly into a deep pool over a sharp edge, and furthermore, according to the author, this complete recovery would be independent of the value of $Z$. . . .

If the value of $Z$ is very great so that $V_0$ is substantially zero, then we should have a lifting of the water surface equal to 5 ft., with no turbulence whatever for the case I have cited.

Mr. Johnson further continues in still another letter:

I might call your attention to the author's application of Equation [10] to Fig. 10 on page 6. As I read this equation, it seems to say that the jump according to Fig. 10 is greater than would be the case in a straight flume (that is, with $Z = 0$) by an amount equal to the difference between the velocity heads of that which would obtain after the jump in a straight flume and that which exists due to some value of $d_0$ greater than $d_2$.

It seems quite obvious that the introduction of a vertical drop in the flume bottom equal to $Z$ would reduce the value of $d_2'$ below that of $d_2$ instead of increasing it. His formula is, however, consistent with his statement that the full velocity head would be recovered when $d_1$ corresponded to the critical depth, for then $d_2$ would equal $d_1$ and the rise in surface elevation would be that due to the difference between the velocity heads. This is of course sufficiently wild to require no demonstration of its incorrectness.

Mr. Johnson has plotted a curve (Fig. 12) showing how the results came out graphically. I am merely putting these points

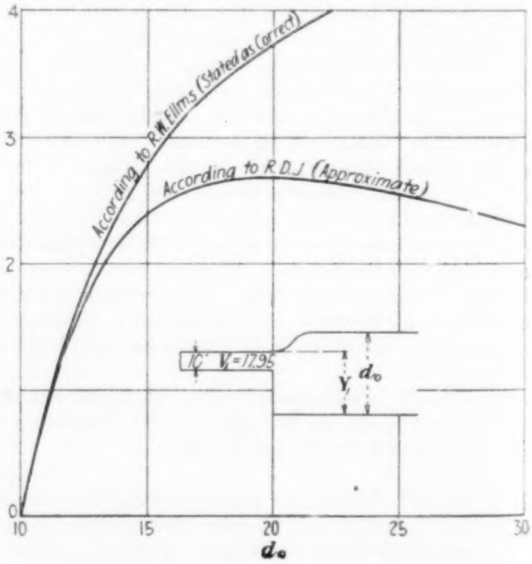


FIG. 12

in at this time, thinking that the author may himself be able to explain the matter. I suspect, however, that these results are merely such as are generally to be expected from an empirical formula based on a relatively narrow range of experimental results when we try to apply the empirical equation to extreme conditions, and that is where they begin to fall down.

I do not want to be understood as submitting these suggestions

in a critical spirit, because, as I said, I have not been able to give the paper enough study to warrant that.

In closing, I want to express my appreciation of the work by the author. I think he deserves much credit for the large amount of experimentation he has put into this and the considerable time he has expended in formulating the results empirically. And he should not be criticized for not having obtained a rational solution. But I am hoping that he may be able to supply further rational analysis of his results in the future. I think that we all ought to encourage just this kind of work on the part of our active engineers, as it is just what the hydraulic art needs, and I say "art" advisedly.

R. L. Daugherty.[7] I have not had time to analyze this paper completely; however, only the first equation is a rational one and all the others are purely empirical without any rational basis whatever. Like Mr. Moody, I should prefer to see a rational analysis made first which would be very general in its scope and would include all dimensions and all cases, and then we should modify that in the light of such experimental data as we should have before us.

I agree also with Mr. Moody that the dotted line showing the path of the center of mass is of very little or no significance. It is the surface curve that really tells the whole story.

I should hope to see more work done in the line of making a rational analysis and then see how that would have to be modified in slight ways in the light of this experience.

I might at this time add something else, which is a side issue. The failure of the St. Francis Dam in California is perhaps one of the most extensive hydraulic experiments of which we are aware.

It seems to me a great pity, so long as the experiment had to come about accidentally, that we could not have taken some real data on it. If it had happened in the daytime instead of at midnight, and if there could have been some observers who could have taken pictures, preferably with a moving-picture camera, or if we could have had some of these gages described in the paper to give us a record of what happened, it would have added enormously to our knowledge of this problem of non-uniform flow, because this paper is a special case of non-uniform flow.

As I see it, this case in California involved two types of non-uniform flow. One is the hydraulic jump that the paper describes, because the depth of the water some distance down the canyon below the dam was greater than the depth of the water immediately below the dam, so there was a hydraulic jump on a large scale. We know that, because the sides of the canyon were previously well covered with brush. Now as you walk down the canyon you see bare, almost polished, rocks to a height of 100 ft. on either side, and we can tell from that what the water surface must have been. So we know that there was a hydraulic jump.

I hope with what we have it will be possible for some careful surveys to be made so that we can perhaps fix the water surface from the evidence we have there. There was a big hydraulic jump below the dam. Then as you go down the stream we have the other phenomenon which is generally known as the "bore," where we have almost a vertical water surface advancing rapidly down the canyon. If we could have had complete data on that, it would be of great value. But I hope that even as it is we may rescue a little information from what happened there from the evidence that has been left behind.

I also wish to thank the author for the work he has done on this subject. It is an important subject, one that has been but very little investigated in reality, and he has added a great deal of real value to our knowledge of it by the careful data he has presented, and it is a very hopeful start in what we trust will be a solution of the problem.

R. L. Sackett.[8] This is a very valuable contribution to the study of hydraulic jump. This phenomenon has become of considerable importance during the last few years, first, as a method of absorbing energy, and now as a means of mixing chemicals preliminary to precipitation in water purification. I think this is a very natural method of approach. Certain data were obtained, and the application of an empirical formula to fit them is quite in line with the usual method of attacking problems of this kind.

The inferences that they have made are sound. We ought to proceed, on the strength of what we have already obtained, to a further analysis by mathematical methods, which should lead us to a final analysis and a solution which would apply to any conditions.

The criticism has been made that the locus of the center of mass was deceptive, or at least of no importance. If we have a given condition such as one depth of flow and a given slope, then of course it is true that the center of mass is not the locus of the center of energy in the consecutive sections. At the same time there is, under a given condition, a very close relation between the locus of the center of mass and the locus of the center of energy and the surface contour. They are all related. If you vary the conditions, you will change the locus of the center of gravity of the section, you will change the locus of the center of energy, and you will change the surface curve, so that while it does not represent anything of great importance, it is related to those factors that are of importance.

We have just built a hydraulic jump at the college, purely for the purpose of absorbing energy, so the erosion below it in an earth canal such as used in irrigation would not be of a character to cut back underneath the concrete and thus endanger it. This subject is therefore of interest to us. Our conditions vary a little, in that the channel below the jump is widened so that it is slightly wider than the channel of approach. The slope of the channel is fixed, but there is an opportunity there to carry on experiments.

### Author's Closure

The author is indebted to the men who have so generously contributed to the discussion of his paper and wishes to express his appreciation for the work they have done, and the helpful attitude they have taken toward the development of a rational solution for this problem.

The empirical equations which the author derived from experimental work satisfied the need for a ready and "exact" method for calculating the tail-water depth of the hydraulic jump when it is produced in sloping and expanding flumes. Formula [10] conforms strictly with present practice in hydraulic engineering. It is substantiated by actual test data which cover a fairly wide range of experimental work. The two slopes tested in the thesis work gave an average deviation of about 6.2 per cent, while a third slope tested by A. G. Levy and J. W. Ellms gave an average of only 2.9 per cent deviation from the corresponding depths as computed by formula [10]. Bidone's original experiments were conducted in a flume which had a slope of about 0.02 ft. per ft. All of his readings were much too great to compare favorably with the depths as computed by the momentum formula. However, if formula [10] is used to correct his results for a sloping flume, a much better agreement between his measured depths and the computed depths will be found.

In the process of developing this empirical formula, the author

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followed what seemed to him a logical procedure. It is evident that the same reasoning here resorted to cannot be applied when a rational solution is desired. In the discussion and conclusion to the paper, he made an attempt to justify formula [10], and tried to establish some sort of a logical reasoning process which he hoped might finally lead to the true rational solution. He is not surprised that the individual steps should be misleading. Obviously, Fig. 9 is only theoretically possible. As drawn, the friction and sudden expansion losses are great enough to offset almost entirely the gain in head. The curve plotted by Mr. Johnson illustrates this loss in head very clearly. A similar loss in head would be experienced for the condition pictured in Fig. 10.

However, by making the assumptions based on the foregoing theoretical conclusions, the author was able to eliminate the automatic effect of "change of section" experienced with jumps produced in sloping flumes. His deductions were correct, because by making these steps he discovered that by adding the velocity-head term to the depth $d_2$, as calculated by the momentum formula, he obtained formula [10], which contains only one empirical constant and which satisfies all the data far better than formula [3].

It must be remembered that if a flume in which a jump is produced has even a slight slope to it, the discharge of the water above the jump is, theoretically at least, into a body of water of infinite size. A gradual slope of the flume affords excellent diffusing conditions for the water just below the jump, and therefore almost a perfect conversion of velocity head into static head results. Here, friction retards the flow in the usual manner. As the angle of the flume increases, the impact or shock losses increase, and consequently it becomes more and more difficult to regain the velocity head. On this basis a separate "diffusion factor" should be entered into formula [10] which varies with the slope, and which is now an integral part of the constant $c$.

Aside from this action there exists a loss of energy which is inherent in the process of producing the jump in a sloping flume. This loss is due to the change of direction of velocity after impact, and, so far, the author has not been able to account for it by a rational analysis. The constant $c$ in formula [9] at present takes care of this condition in an empirical way. A study of the rise and fall of the center of mass of the water may aid in a rational solution of the problem. The author made use of it only because he thought it might furnish some clew to the solution of this phenomenon. All methods that he has tried for a rational solution failed to give anything but indeterminate results.

The author is in hope that subsequent discussions will clear the matter up, for he firmly believes that the empirical solution will eventually yield to a rational one.

# Notes on "A New Method of Separating the Hydraulic Losses in a Centrifugal Pump"[1]

By MICHAEL D. AISENSTEIN,[2] BERKELEY, CALIF.

THE author has received queries as to how to proceed when $\left[Q, \frac{h - h_0}{Q - Q_0}\right]$ does not plot as a straight line for the entire range of $Q$, which is a very common occurrence. This can be best illustrated by an example.

Given the characteristics of an 8-in. two-stage pump, operating at 960 r.p.m., the inlet diameter of the impeller $d_1 = 9$ in., the outlet diameter $d_2 = 21$ in.

First tabulate the values of $Q$ and the corresponding values of $h$, as shown in Table 3.

The points $\left[Q, \frac{h - h_0}{Q - Q_0}\right]$ when plotted do not lie on a continuous straight line but form two straight lines $AB$ and $BC$, Fig. 4$a$. Since the analysis is based on the consideration of the point of the maximum efficiency, the points lying on the $AB$ portion should be included only. Following the procedure indicated in the paper, we have

$$3a + 4800b = -0.1851$$

$$2a + 5200b = -0.1737$$

Solving for $a$ and $b$,

$$a = -0.02146$$

$$b = -0.00002515$$

Substituting these values in the equation

$$\frac{h - h_0}{Q - Q_0} = a + b\,Q$$

and solving,

$$h = 237.8 + 0.05902\,Q - 0.00002515\,Q^2$$

Further, $u_2 = 88$ ft. per sec. and $u_1 = 37.7$ ft. per sec. From Equation [16] of the paper, $A = 196.6$ per stage, or 393.2 for two stages.

From Equation [22],

$$D = \sqrt{393.2 - 237.8} = 12.48$$

The point of maximum efficiency occurs at 2200 gal. per min., therefore

$$E = \frac{2200 \times 0.00002515}{12.48} = 0.00443$$

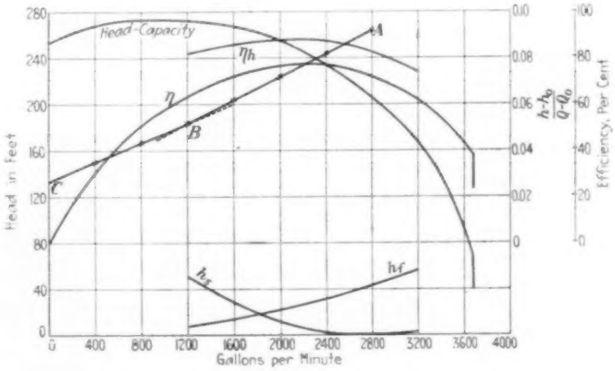


Fig. 4$a$ Characteristics of 8-In. Two-Stage Pump Used in Example

From Equation [24]

$$c = 0.00000553$$

From Equation [23]

$$B = -0.05148$$

**Substituting all these values in Equation [15],**

$$h = (393.2 - 0.05148\,Q) - \underset{\text{(Friction loss)}}{0.00000553\,Q^2} - \underset{\text{(Shock loss)}}{(12.48 - 0.00443\,Q)^2}$$

The friction and shock losses are now to be entered in Table 3.

It is evident that in this case the losses are determined for the region covered by the $AB$ line only. This being the region of the maximum efficiency, gives the desired information to the designer.

TABLE 3

| No. | $Q$, g.p.m. | $h$, ft. | $Q - Q_0$ | $h - h_0$ | $\frac{h - h_0}{Q - Q_0}$ | $h'$, ft. | $\Delta h$, ft. | $hf$, ft. | $hs$, ft. | $H$, ft. | $\eta h$, per cent |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 253 | −3200 | 84 | −0.0262 | ... | ... | .. | .... | ... | .. |
| 2 | 400 | 268 | −2800 | 99 | −0.0354 | ... | ... | .. | .... | ... | .. |
| 3 | 800 | 273 | −2400 | 104 | −0.0432 | ... | ... | .. | .... | ... | .. |
| 4 | 1200 | 272 | −2000 | 103 | −0.0515 | 271.6 | +0.4 | 7.96 | 51.4 | 331.4 | 82.1 |
| 5 | 1600 | 268 | −1600 | 99 | −0.0619 | 267.7 | +0.3 | 14.2 | 29.1 | 311.3 | 86.0 |
| 6 | 2000 | 255 | −1200 | 86 | −0.0717 | 255.5 | −0.5 | 22.1 | 13.1 | 290.2 | 87.7 |
| 7 | 2400 | 234 | − 800 | 65 | −0.0812 | 234.4 | −0.4 | 31.9 | 3.4 | 269.3 | 86.9 |
| 8 | 2800 | 206 | − 400 | 37 | −0.0925 | 205.9 | +0.1 | 43.3 | 0.0064 | 249.3 | 82.6 |
| 9 | 3200 | 169 | 0 | 0 | ...... | 169.1 | −0.1 | 56.6 | −2.96 | 228.6 | 73.8 |

[1] Supplementing the author's paper of that title published in Trans. A.S.M.E., vol. 50, no. 3, January-April, 1928.

[2] Hydraulic Engineer, Byron Jackson Pump Mfg. Co. Jun. A.S.M.E.

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# Friction in Dredge Pipes

By JAMES H. POLHEMUS,[1] PORTLAND, OREG., and JOHN R. DuPRIEST,[2] MINNEAPOLIS, MINN.

*This paper presents some information on pipe friction for dredge pipe 29 in. inside diameter and with velocities up to about 20 ft. per sec. The data were obtained during some recent tests of large hydraulic dredge pumps, and on account of the large size of the pipe and the high velocities encountered it was thought worth while to present the information for the benefit of others engaged in dredge work.*

*An analysis is also given of the data showing how the equation for loss of head in pipe lines can be modified so as to give a constant friction factor as velocity varies instead of having both velocity and friction factor vary in the equation.*

THE subject of pipe-line friction is always an interesting one to those engineers engaged in any way with the handling of liquids, and a great many experiments have been made under different conditions with different fluids and with various kinds and sizes of pipe to determine the loss owing to so-called pipe friction.

Some time ago the writers made very thorough tests of several large dredge pumps to gather data for use in designing the main pump for the Port of Portland's new Diesel-electric dredge *Clackamas*. The pump on this new dredge was to have a greater operating range than any dredge pump of its class previously built, and for this reason it was very desirable to obtain the best information possible before getting out the designs.

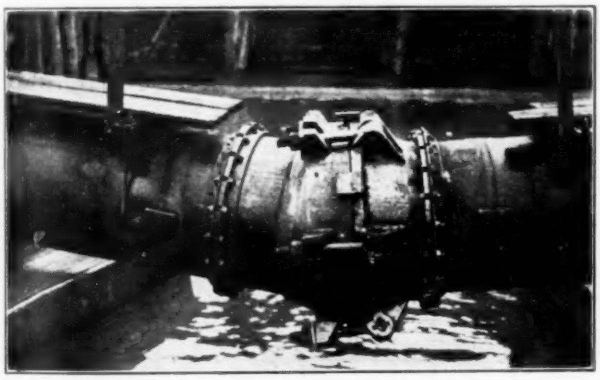

FIG. 1 FLEXIBLE RUBBER SLEEVE CONNECTOR

During these pump tests the opportunity was presented to obtain other valuable information pertaining to the operation of pipe-line dredges, and this paper presents some information based on data gathered at that time.

It is not often that thorough tests can be conducted on pipes as large as 29 in. inside diameter and with velocities as high as 20 ft. per sec., and for this reason it is hoped that the results obtained from these tests will add something to the literature on the subject of pipe-line friction. The pipe used in these tests was butt-welded steel pipe $^1/_2$ in. thick made up in 30-ft. lengths with flanges riveted on it. The pipe was bolted up in 90-ft. sections, and rubber sleeve connectors about 3 ft. long were used between the 90-ft. sections. Fig. 1 shows a picture of one of the flexible rubber connectors.

The length of pipe line between gages used for determining pipe friction was 1046 ft. and included 11 rubber sleeve connectors. The pipe had been in use for only a short time, was highly polished, and was probably as smooth as it is possible to get dredge pipes. The rubber sleeves were practically new and in first-class condition. The pipe line can therefore be considered as in the best condition throughout.

Fig. 2 shows a diagrammatic arrangement of the set-up for the tests, and it will be noted that on the end of the floating line a number of nozzles were attached. By varying the size of the nozzles, together with changes in speed of the pump, any conditions of pressure and velocity could be obtained within the capacity of the pump. Data were taken during three different

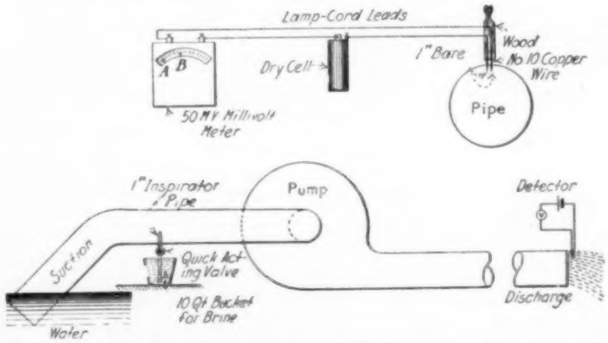


FIG. 2a SCHEME OF ELECTRICAL METHOD FOR VELOCITY MEASUREMENTS

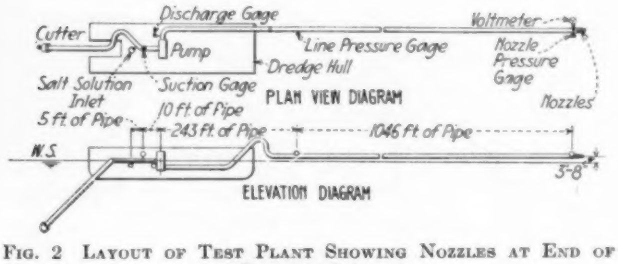


FIG. 2 LAYOUT OF TEST PLANT SHOWING NOZZLES AT END OF FLOATING LINE

pump tests, and it is believed that sufficient information is available to leave little doubt as to the accuracy of the results obtained.

## MEASURING PIPE-LINE VELOCITY

The value of the results presented in this paper depends on the accurate determination of the velocity of flow through the pipe, and a few words of explanation here will show how the velocity was obtained.

The method used to determine the velocity of flow through the pipe line is known by dredge testing engineers as the salt-solution method and is carried out as follows: Two insulated electrodes (Fig. 2a) are inserted in the pipe line, separated by a few inches. A dry cell and millivoltmeter are connected between the electrodes. The resistance of the circuit is such that, with ordinary river water flowing, a small deflection is shown on the voltmeter,

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but when a salt solution is introduced into the stream and passes the electrodes, the deflection of the voltmeter increases considerably owing to the better conductivity of the salt water. The sensitiveness of the method will be appreciated when it is known that the resistance of ordinary river water will vary from about 2000 to 5000 ohms per cc., whereas the resistance of a 5 per cent solution of pure salt water will be about 15 ohms per cc.

During these tests about 2 gal. of saturated salt water was introduced into the pipe line at each velocity test. Two velocity determinations were made for each run, and when the two did not agree closely, a third test was usually made.

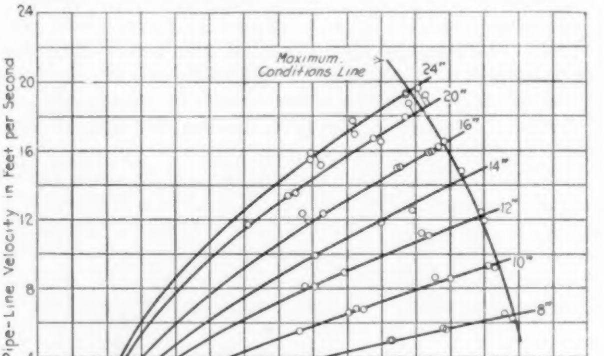


Fig. 3 Curves T1–6

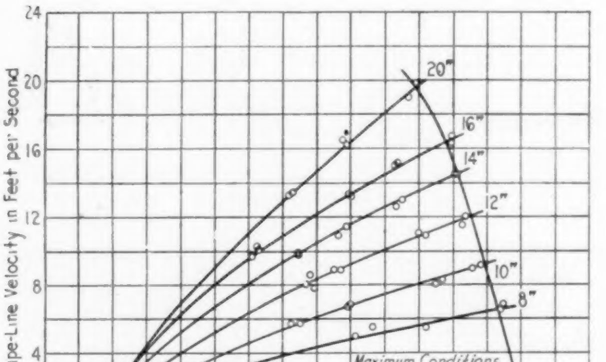


Fig. 4 Curves T2–6

The following readings were taken during the tests: Time required for the salt solution to enter the pipe; time required for the salt solution to pass the electrodes; time from the opening of the valve to admit the salt solution until the salt water reached the electrodes, i.e., when the voltmeter needle first began to change. The velocity was then found from the following equation

$$\text{Average velocity} = \frac{1}{2}\left(\frac{D}{T} + \frac{D}{T + Y - X}\right)$$

where $D$ = distance in feet between point where salt water was introduced and the location of electrodes

$X$ = number of seconds to introduce salt water

$Y$ = number of seconds for salt solution to pass voltmeter

$T$ = number of seconds from time of opening salt-water valve until solution reached electrodes.

The velocities as found by this method are plotted in Figs. 3, 4, and 5, and the results obtained give good curves. On account of having families of curves it is very much easier to detect errors and also much easier to give proper locations to the curves. A careful analysis of the results by cross-checking with other curves showing different data for the same tests indicated that, for the points which do not fall on the curves, speeds are in error in some cases and velocities are in error in others. Altogether the data for the three tests are very consistent, and certainly very little change could be made in the locations of the various curves.

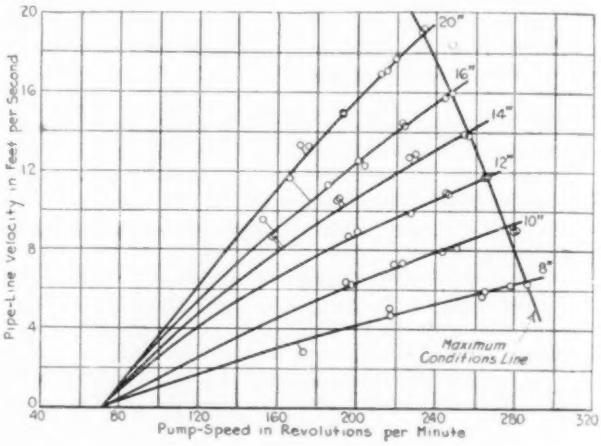


Fig. 5 Curves T3–6

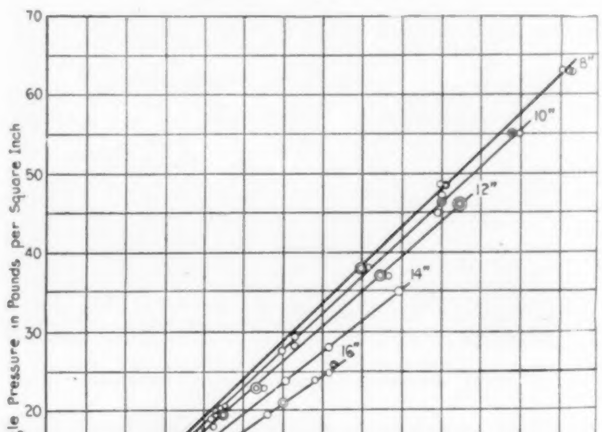


Fig. 6 Curves T1–7

### Head Lost in Line

The difference between the line pressure, which was taken about 40 ft. behind the dredge, and the pressure just ahead of the test nozzle should represent the head lost in the 1046 ft. of floating line. In the first efforts to study this data the values as observed were subtracted to give head lost in the line, but it was soon found that slight errors of observations caused a large percentage of error when dealing with the small heads lost at

low velocities. To reduce the effect of observation errors curves were plotted, as shown in Figs. 6, 7, and 8, using line pressure as abscissas and nozzle pressure as ordinates.

It will be noted that the curves are essentially straight lines, except for the large nozzles, and as the scales chosen place the curves near the 45-deg. position there is little chance for error

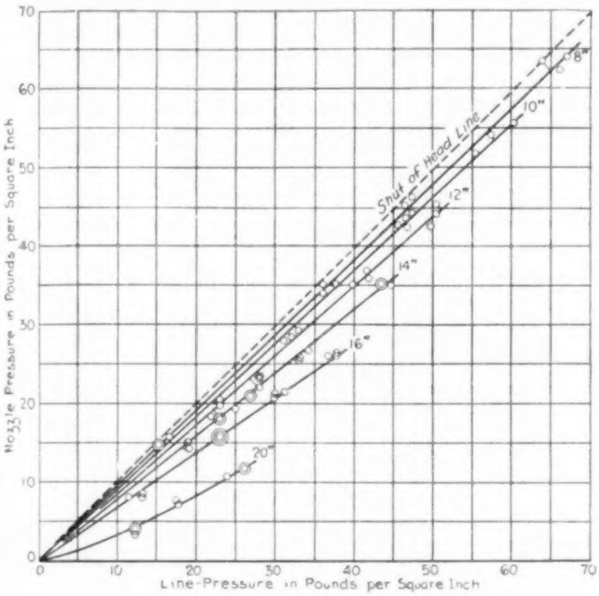


Fig. 7 Curves T2–7

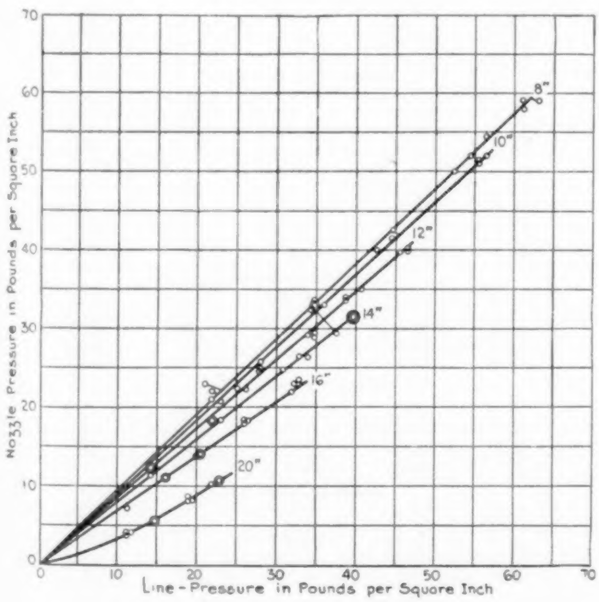


Fig. 8 Curves T3–7

in the location of these curves. The results obtained by use of these curves confirm this as they are remarkably consistent. The friction factors were first found by use of the well-known equation

$$H = \frac{flv^2}{2gd}$$

where $H$ = head lost in line in feet of water
$l$ = length of line in feet

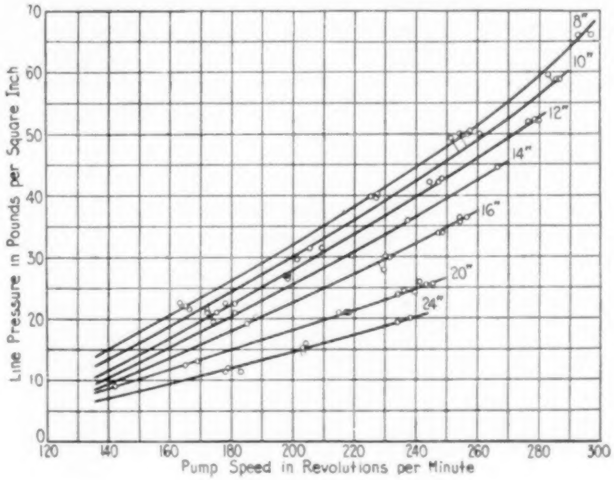


Fig. 9 Curves T1–17

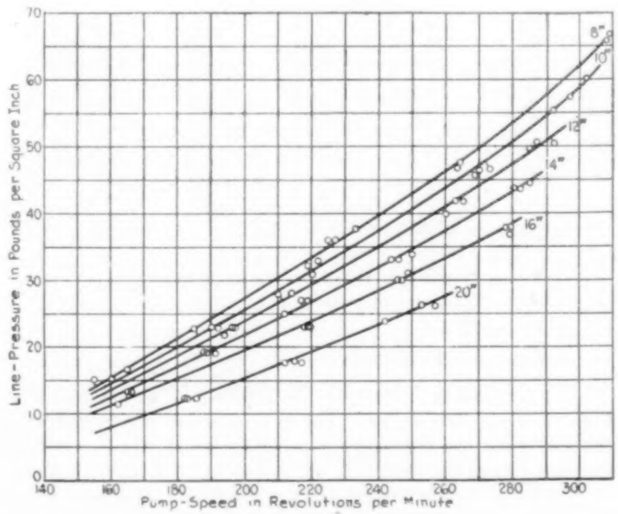


Fig. 10 Curves T2–17

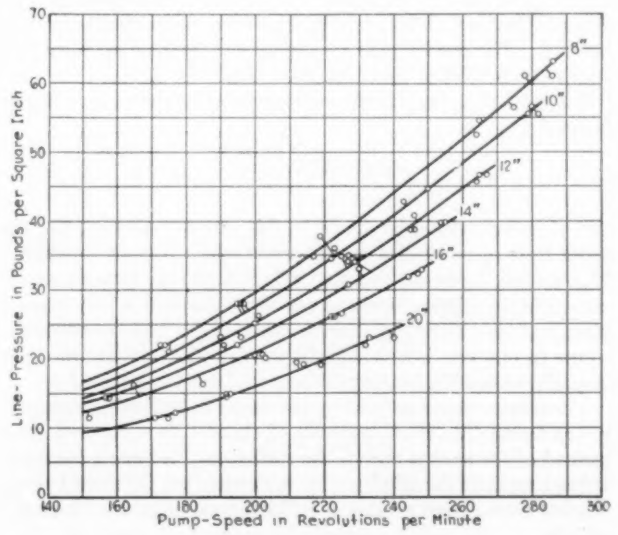


Fig. 11 Curves T3–17

TABLE 1 HEAD LOSS DUE TO PIPE FRICTION

| Line pressure, lb. per sq. in. | Nozzle pressure, lb. per sq. in. | Head lost,* ft. of water | Pump speed, r.p.m. | Pipe line velocity, ft. per sec. |
|---|---|---|---|---|
| Nozzle diameter 10 in. | | | | |
| 30 | 27.7 | 5.30 | 219 | 6.5 |
| 35 | 32.2 | 6.45 | 236 | 7.1 |
| 40 | 36.9 | 7.15 | 252 | 7.6 |
| 45 | 41.5 | 8.06 | 268 | 8.2 |
| 50 | 46.0 | 9.21 | 282 | 8.7 |
| 55 | 50.6 | 10.2 | 296 | 9.1 |
| 60 | 55.3 | 10.8 | 308 | 9.5 |
| Nozzle diameter 12 in. | | | | |
| 15 | 13.0 | 4.61 | 173 | 6.8 |
| 20 | 17.5 | 5.76 | 191 | 7.7 |
| 25 | 21.9 | 7.15 | 209 | 8.5 |
| 30 | 26.3 | 8.53 | 226 | 9.2 |
| 35 | 30.6 | 10.2 | 244 | 10.0 |
| 40 | 35.0 | 11.5 | 260 | 10.6 |
| 45 | 39.4 | 12.9 | 276 | 11.3 |
| 50 | 43.8 | 14.3 | 291 | 11.9 |
| Nozzle diameter 14 in. | | | | |
| 10 | 7.8 | 5.08 | 158 | 7.4 |
| 15 | 11.7 | 7.60 | 179 | 8.6 |
| 20 | 15.7 | 9.91 | 198 | 9.7 |
| 25 | 19.6 | 12.5 | 217 | 10.7 |
| 30 | 23.5 | 15.0 | 236 | 11.7 |
| 35 | 27.5 | 17.3 | 254 | 12.7 |
| 40 | 31.4 | 19.8 | 271 | 13.6 |
| 45 | 35.4 | 22.2 | 288 | 14.4 |
| Nozzle diameter 16 in. | | | | |
| 10 | 6.9 | 7.15 | 162 | 9.4 |
| 15 | 10.4 | 10.6 | 186 | 11.0 |
| 20 | 13.9 | 14.1 | 208 | 12.4 |
| 25 | 17.4 | 17.5 | 230 | 13.7 |
| 30 | 21.0 | 20.8 | 250 | 14.9 |
| 35 | 24.3 | 24.7 | 270 | 16.0 |
| Nozzle diameter 20 in. | | | | |
| 10 | 3.4 | 15.2 | 168 | 12.0 |
| 15 | 5.7 | 21.4 | 200 | 14.3 |
| 20 | 8.5 | 26.5 | 231 | 16.4 |
| 25 | 11.4 | 31.4 | 260 | 18.2 |

* Lost heads are for 1046 ft. of dredge pipe 29 in. inside diameter.

$v$ = velocity of water in feet per second
$d$ = diameter of pipe in feet
$g$ = 32.2
$f$ = friction factor.

Data for finding $f$ are given in Tables 1, 2, and 3, and were found in the following way: For given selected line pressures at the first gage, pressures at the second gage or nozzle pressures were read from curves T1–7, T2–7, and T3–7, Figs. 6, 7, and 8. For the same line pressures, pump speeds were read from curves T1–17, T2–17, and T3–17, Figs. 9, 10, and 11. For the pump speeds obtained, pipe-line velocities were then read from curves T1–6, T2–6, and T3–6, Figs. 3, 4, and 5. With these data as given in Tables 1, 2, and 3, values were calculated for the friction factor $f$. The results were very consistent and agreed very well with some published data that were available.

Curve T2–25, Fig. 12, shows the relation between the friction factor $f$

$$f = \frac{2gd \times H}{l \times v^2}$$

and pipe-line velocity as found in this way for one test, and the other tests gave similar curves with values just as consistent. The writers, however, feel that there should be little cause for change in the friction factor as velocity changes in a very smooth pipe, and also, since the variable value of $f$ is more troublesome to use in practice, it was thought worth while to study the data carefully to see if a better relation could not be obtained.

The results were analyzed by the use of logarithmic paper, and it was found that if an exponent of about 1.75 were used for $v$ instead of the second power, the coefficient $f$ became a constant. It has long been thought by some engineers that the second power was not correct, and a value of 1.75 has been suggested by several writers.

In Fig. 13 all of the data for lost head against pipe-line velocity

TABLE 2 HEAD LOSS DUE TO PIPE FRICTION

| Line pressure, lb. per sq. in. | Nozzle pressure, lb. per sq. in. | Head lost,* ft. of water | Pump speed, r.p.m. | Pipe line velocity, ft. per sec. |
|---|---|---|---|---|
| Nozzle diameter 10 in. | | | | |
| 30 | 27.5 | 5.76 | 215 | 6.6 |
| 35 | 32.1 | 6.70 | 232 | 7.2 |
| 40 | 36.7 | 7.61 | 248 | 7.7 |
| 45 | 41.4 | 8.30 | 264 | 8.2 |
| 50 | 46.0 | 9.23 | 278 | 8.6 |
| 55 | 50.5 | 10.4 | 291 | 9.0 |
| 60 | 55.3 | 10.9 | 302 | 9.3 |
| Nozzle diameter 12 in. | | | | |
| 15 | 12.9 | 4.85 | 165 | 6.6 |
| 20 | 17.3 | 6.23 | 185 | 7.6 |
| 25 | 21.6 | 7.85 | 204 | 8.5 |
| 30 | 26.0 | 9.23 | 222 | 9.3 |
| 35 | 30.4 | 10.6 | 240 | 10.1 |
| 40 | 34.8 | 12.0 | 257 | 10.8 |
| 45 | 39.1 | 13.6 | 273 | 11.4 |
| 50 | 43.5 | 15.0 | 288 | 12.0 |
| Nozzle diameter 14 in. | | | | |
| 15 | 11.7 | 7.61 | 171 | 8.8 |
| 20 | 15.7 | 9.92 | 192 | 10.0 |
| 25 | 19.8 | 12.0 | 213 | 11.2 |
| 30 | 23.8 | 14.3 | 232 | 12.1 |
| 35 | 27.8 | 16.6 | 251 | 13.1 |
| 40 | 31.8 | 18.9 | 269 | 13.8 |
| 45 | 35.7 | 21.4 | 285 | 14.6 |
| Nozzle diameter 16 in. | | | | |
| 10 | 6.6 | 7.85 | 153 | 9.0 |
| 15 | 10.0 | 11.5 | 178 | 10.8 |
| 20 | 13.5 | 15.0 | 202 | 12.3 |
| 25 | 17.0 | 18.5 | 225 | 13.7 |
| 30 | 20.4 | 22.2 | 246 | 14.8 |
| 35 | 23.8 | 25.8 | 267 | 15.9 |
| Nozzle diameter 20 in. | | | | |
| 10 | 2.7 | 16.8 | 171 | 12.1 |
| 15 | 5.5 | 21.9 | 197 | 14.5 |
| 20 | 8.2 | 27.2 | 224 | 16.8 |
| 25 | 11.0 | 32.3 | 248 | 18.8 |

* Lost heads are for 1046 ft. of dredge pipe 29 in. inside diameter.

TABLE 3 HEAD LOSS DUE TO PIPE FRICTION

| Line pressure, lb. per sq. in. | Nozzle pressure, lb. per sq. in. | Head lost,* ft. of water | Pump speed, r.p.m. | Pipe line velocity, ft. per sec. |
|---|---|---|---|---|
| Nozzle diameter 10 in. | | | | |
| 32.2 | 29.6 | 6.00 | 215 | 6.9 |
| 39.0 | 35.9 | 7.16 | 235 | 7.7 |
| 46.8 | 42.7 | 9.47 | 255 | 8.5 |
| 54.9 | 50.3 | 10.6 | 277 | 9.3 |
| Nozzle diameter 12 in. | | | | |
| 25.2 | 22.0 | 7.40 | 200 | 8.8 |
| 31.0 | 27.1 | 9.01 | 220 | 9.7 |
| 35.9 | 31.2 | 10.9 | 235 | 10.4 |
| 41.0 | 35.6 | 12.5 | 250 | 11.1 |
| 47.0 | 40.8 | 14.3 | 267 | 11.8 |
| Nozzle diameter 14 in. | | | | |
| 14.1 | 11.5 | 6.00 | 155 | 7.6 |
| 18.8 | 14.8 | 9.24 | 180 | 9.4 |
| 24.5 | 19.6 | 11.3 | 205 | 11.0 |
| 31.5 | 25.4 | 14.1 | 230 | 12.5 |
| 40.2 | 32.1 | 18.7 | 257 | 14.1 |
| Nozzle diameter 16 in. | | | | |
| 13.7 | 9.3 | 10.2 | 165 | 9.6 |
| 17.5 | 11.6 | 13.6 | 185 | 11.3 |
| 21.9 | 14.8 | 16.4 | 205 | 12.9 |
| 26.8 | 18.5 | 19.2 | 225 | 14.4 |
| 33.1 | 23.0 | 23.4 | 248 | 16.7 |
| Nozzle diameter 20 in. | | | | |
| 11.7 | 4.0 | 17.8 | 175 | 12.9 |
| 14.0 | 5.1 | 20.6 | 190 | 14.6 |
| 16.7 | 6.7 | 23.1 | 205 | 16.3 |
| 19.9 | 8.2 | 27.0 | 220 | 17.8 |
| 23.0 | 9.7 | 30.7 | 234 | 19.1 |

* Lost heads are for 1046 ft. of dredge pipe 29 in. inside diameter.

are plotted for the three tests. The large circles are plotted from the equation

$$H = \frac{flv^n}{2gd}$$

where $n$ = 1.75, and
$f$ = 0.0280

and the small circles are test-data points. Considering the large scales used in plotting these data, the test points fall remarkably close to the mathematical curve.

There are about one-hundred points from test, plotted in Fig. 13, covering three tests made on different days and each test lasting between 12 and 18 hours. The points grouped around any given velocity, say 12 ft. per sec., represent conditions for several different speeds and pressures at the pump.

In view of the large amount of data available, the length of time of the tests requiring changing observers every eight hours or less as the dredge crew changed, the results are very consistent, and it is believed that they will be found to be entirely trustworthy.

While the results from these tests give a friction factor of 0.028 for 29-in. dredge pipe in good condition, it must be remembered

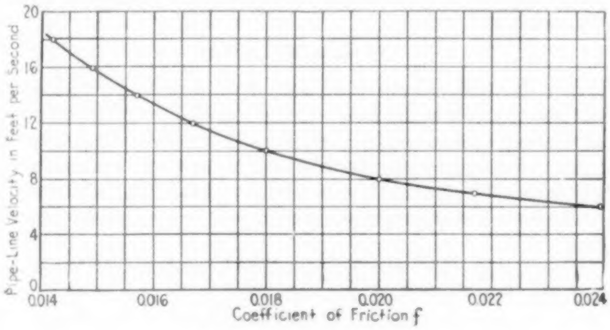


Fig. 12 Curves T2-25

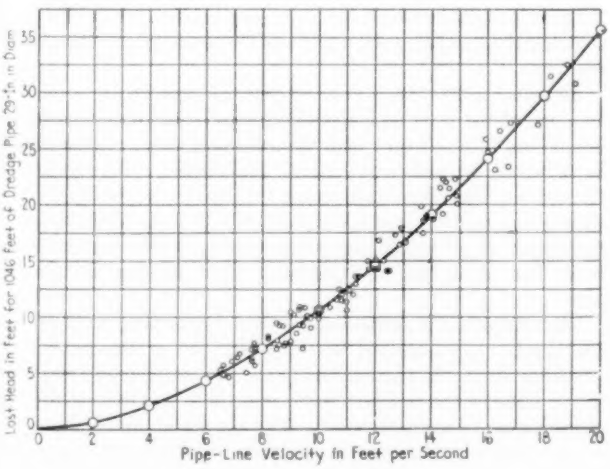


Fig. 13 Curves CC-14B

that the rubber sleeve connections between the 90-ft. sections of pipe cause some loss owing to disturbance to flow, and therefore smooth steel pipe with flush joints of uniform diameter should give a slightly lower coefficient.

The shore pipe uses metal slip joints, and while each joint probably offers much less resistance to flow than a rubber sleeve, the joints come every 30 ft., and the total resistance in any long line will probably agree very closely with the results obtained by use of the equation given.

### Conclusions

While the old method of using a variable friction factor depending on the velocity, as shown in Fig. 12, will give good results, the constant friction factor seems more logical. The values for $f$ and also for $n$, as found from these tests, are for pipe 29 in. inside diameter and may not hold for other sizes of pipe, as the head lost may not vary as $\frac{1}{d}$.

It is hoped that in the near future tests can be conducted on other sizes of dredge pipe and compared with the results given in this paper, to find out if the head lost owing to friction is inversely proportional to the diameter or whether the equation should take the form

$$H = \frac{flv^n}{2gd^x}$$

If it is found that $d$ should have an exponent slightly different from 1, the values for $f$ and $n$ as found in the foregoing, may change slightly. However, it is believed that suitable values

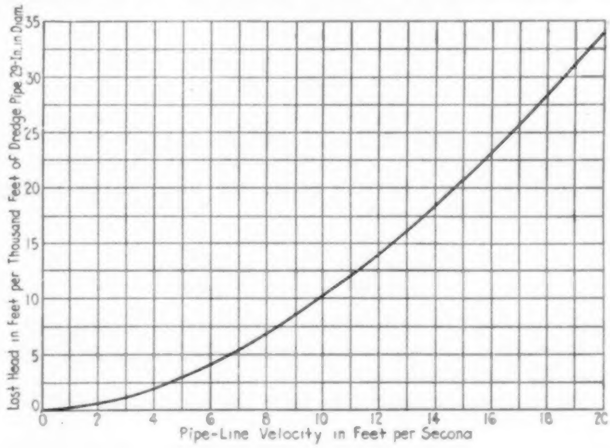


Fig. 14 Curves CC-14C

can be found for both $n$ and $x$ which will give a constant value for $f$ for all sizes of dredge pipe.

It is hoped that engineers who have accurate test data available will make comparisons with this work to check the accuracy of the results as given, and the authors will be very glad to discuss the subject further with any engineers interested in this problem.

## Discussion

Michael D. Aisenstein.[3] It is interesting to compare the results obtained by the authors with the results predicted from the equations of flow embodying the Reynolds criterion. This may be accomplished as follows:

The exponential formula, in general, derived by means of the principle of dynamic similarity, is

$$h_f = Kl \frac{v^n}{d^{3-n}\ \nu^{n-2}} \qquad [1]$$

or

$$h_f = \frac{l}{d}\frac{v^2}{2g}\,\phi\left(\frac{vd}{\nu}\right) \qquad [2]$$

where $v$ = velocity of flow in feet per sec.
$l$ = pipe length in feet
$h$ = head in feet
$\nu$ = kinematic viscosity in English units, and
$g$ = gravitational constant = 32.2.

For steamline flow, that is, when $vd/\nu < 2000$, the coefficient of friction

$$\phi\left(\frac{vd}{\nu}\right) = \frac{64}{\frac{vd}{\nu}} \qquad [3]$$

[3] Hydraulic Engineer, Byron Jackson Pump Mfg. Co., Berkeley, Calif. Jun. A.S.M.E.

For turbulent flow, or when $vd/\nu > 2000$, the writer, from available experimental data of different authorities, determined the coefficient to be:[4]

$$\phi\left(\frac{vd}{\nu}\right) = \frac{0.167}{\left(\frac{vd}{\nu}\right)^{0.170}} \qquad [4]$$

Substituting in [2],

$$h_f = 0.167\, \nu^{0.170} \frac{l}{d^{1.170}} \frac{v^{1.830}}{2g} \qquad [5]$$

or for clean water having a kinematic viscosity of 0.00001077 at 68 deg. fahr.,

$$h_f = 0.0239 \frac{l}{d^{1.170}} \frac{v^{1.830}}{2g} \qquad [6]$$

Inspecting Equations [1], [5], and [6], one can see that the exponents for $d$ and $v$ are mutually related, and have actually a physical meaning. For this reason the writer suggests using formula [5] or [6] instead of

$$h = \frac{flv^n}{2gd^x} \quad \text{or} \quad h = \frac{flv^n}{2gd}$$

with exponent 1.75, as both these formulas are rather arbitrary.

Moreover it can be seen that formula [5] is more general as the viscosity term is included.

The authors overlooked to state the temperature and kind of water they pumped, and the writer assumes that clean water at temperature of about 60 deg. fahr. was used.

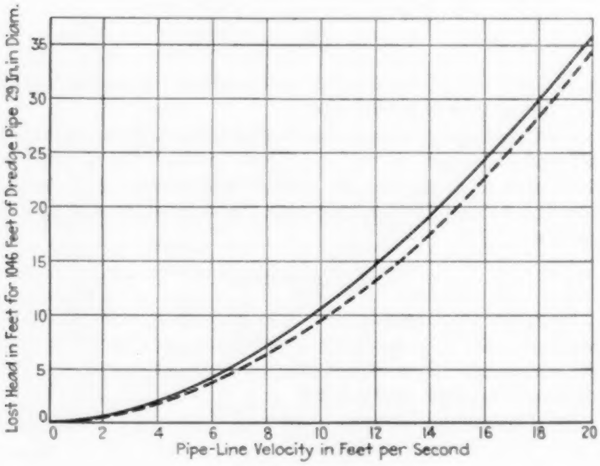


Fig. 15

Full line replotted from Fig. 13. Broken line calculated by means of formula $h_f = 0.0239 \frac{l}{d^{1.170}} \frac{v^{1.830}}{2g}$

Having substituted the different values of velocities in Equation [6] for the same pipe which was used by the authors, the writer obtained a $v$–$h_f$ curve (Fig. 15).

It may be noticed that this curve agrees close enough for engineering purposes with the curve plotted in Fig. 13.

The writer would like to see tests made to obtain the pipe-friction loss for dredged mixtures of different densities, to see if it is possible to predict by means of the Reynolds criterion the pipe friction when the percentage of spoil to be pumped and the screen analysis and density of spoil are known.

[4] Trans. A.S.M.E., vol. 50, no. 3, Jan.-Apr., 1928, paper no. HYD-50-2, p. 6.

O. M. Leland.[5] Would the angles made by the various sections of the pipe either on the shore or on the floating section make very much difference in the friction losses? In the case of a dredge moving around, the pipe line is not moved any more than is necessary, and in the floating section one frequently finds considerable angles in the pipe. On the shore line there are more sections and likely some angles possibly worth considering. I wonder if the authors found any difficulties or variations on account of those angles and whether they reduced the angles to a minimum in all cases.

M. W. Davidson.[6] Was any effort made by the men who made this test to introduce electrodes at different points across the current?

## Authors' Closure

Replying to Mr. Leland, no tests were made to determine the loss due to bends in the line. The line used during the tests was all floating, with no bends. Occasionally the waves from passing boats would cause some disturbance, but this was not serious at any time. The floating line as used in practically all of the work on the river has one right-angle bend only, placed at the donkey scow.

The floating line extending to shore is anchored at the scow, and the line extending from the dredge to the scow swings as the dredge advances and is also lengthened as the dredge advances.

The shore line is made up of 30-ft. lengths, with slip joints, and the line is flexible enough for long, easy bends; Y's are used for splitting the line for making fills and for changing the location of the line.

Replying to Mr. Davidson, no attempt was made to make a traverse of the pipe with the electrodes. This was considered, but it was believed that with the velocities obtained the turbulence would be sufficient to give practically uniform velocity throughout the pipe, considering the length of the line. The electrodes extended into the pipe from 1 to 2 in. This is about the length used when in regular operation, as long electrodes are easily bent or broken by stones and sticks passing through the line.

Mr. Aisenstein's discussion is very interesting and is appreciated. As mentioned in the early part of the paper, the checking up on the friction loss in the dredge pipe line was only a side issue of the real test work, and there was no intention of doing accurate research work. The results obtained, however, were better than had been anticipated, and it was for this reason they were offered, believing they might be of interest to some few engineers.

The authors are well pleased to find that the results agree so closely with Mr. Aisenstein's theoretical equations. The equation proposed in the paper for loss of head was put intentionally in as simple form as possible so as to be used by practical dredge men and its shortcomings were recognized.

Clear water at about 60 deg. was pumped at all times during the tests. No serious effort was made to determine pipe-line friction when pumping material, as it is almost impossible to maintain even approximately constant conditions of flow for any great length of time unless the material being pumped is consistent throughout the swing of the dredge, and even then the line conditions are constantly changing, depending on the skill of the lever man.

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[6] Professor of Mechanical Engineering, University of South Dakota, Vermillion, S. D. Mem. A.S.M.E.

# Flow of Water Over a V-Notch

By JOSEPH TARRANT,[1] SOUTH HARROW, MIDDLESEX, ENGLAND

*In this paper the author presents a formula for finding the flow of water over V-notches with angles ranging from 90 deg. down to 27 deg., which is based on the experimental results given in D. Robert Yarnall's paper on the "Accuracy of the V-Notch-Weir Method of Measurement," presented before the A.S.M.E. in December, 1926. He compares this formula with others which have been proposed, checks it with data obtained by several investigators, and concludes that, within the range of angles specified, it will prove useful. An alignment chart based on the formula is given, from which discharges may easily be read off.*

HAVING occasion recently to look up data on the flow of water over a V-notch, the author read the account of a series of experiments on the flow over notches of various angles carried out by Mr. D. Robert Yarnall, Mem. A.S.M.E., and described by him in a paper[2] which was reprinted in MECHANICAL ENGINEERING of January, 1927.

The experiments were carried out on notches of 90 deg., 53 deg. 8 min., 27 deg., and 13 deg. 8 min., for the purpose of verifying the value of the coefficient $C$ in the formula

$$Q = CH^{5/2}$$

where $Q$ = discharge in cubic feet per minute, and
$H$ = head over weir in inches,

and the tables and curves given in the paper show that the value of $C$ varies according to the head, for each of the four notches tested, and appears to reach a stable value in each case at a head of about 15 in.; in the case of the 90-deg. notch, $C$ varied from 0.303085 at 4.988 in. head to 0.29775 when the head reached 15.0522 in.

In the discussion which followed the paper, Mr. M. P. O'Brien[3] gave, for each notch, a formula with a fixed index, these formulas being as follows:

| Angle | Formula |
|---|---|
| 90° | $Q = 2.48\ H^{2.49}$ |
| 53°8′ | $Q = 1.242\ H^{2.48}$ |
| 27° | $Q = 0.613\ H^{2.475}$ |
| 13°8′ | $Q = 0.3312\ H^{2.42}$ |

$Q$ being in cubic feet per second, and $H$ in feet.

It occurred to the author that such a range of tests as those carried out by Mr. Yarnall might be used for finding a formula which could be used for notches of all angles between the largest and smallest notches, and to this end the experimental results were plotted logarithmically. It was found difficult to obtain a formula of simple type which would cover the whole range from 90 deg. down to 13 deg. 8 min., but the formula

$$Q = 2.415 \tan\left(\frac{\theta + 1.5°}{2}\right) H^{2.485}$$

where $Q$ = cubic feet per second
$H$ = head in feet, and
$\theta$ = angle of the notch in degrees,

gives results which agree very closely with the experimental results on the 90-deg., 53-deg. 8-min., and 27-deg. notches, and may be presumed to hold for all angles between 90 deg. and 27 deg.

In Table 1 discharges calculated by the formula are compared with Yarnall's experimental results.

TABLE 1 DISCHARGE CALCULATED BY THE PROPOSED FORMULA $Q = 2.415 \tan\left(\frac{\theta + 1.5°}{2}\right) H^{2.485}$ COMPARED WITH YARNALL'S EXPERIMENTAL RESULTS

| Notch angle, $\theta$ | Head in ft. | $Q$ (Yarnall) | $Q$ (Calculated) | Error |
|---|---|---|---|---|
| 90° | 1.257 | 4.384 | 4.375 | −0.002 |
| | 1.234 | 4.222 | 4.179 | −0.006 |
| | 1.143 | 3.468 | 3.453 | −0.0044 |
| | 0.9278 | 2.061 | 2.058 | −0.0014 |
| | 0.7634 | 1.2687 | 1.267 | −0.0014 |
| | 0.5931 | 0.6724 | 0.677 | +0.007 |
| | 0.4852 | 0.4099 | 0.4108 | +0.002 |
| | 0.3502 | 0.1825 | 0.1827 | +0.001 |
| 53°8′ | 1.2527 | 2.164 | 2.183 | +0.009 |
| | 1.1516 | 1.756 | 1.771 | +0.0085 |
| | 0.9784 | 1.172 | 1.186 | +0.012 |
| | 0.7656 | 0.6376 | 0.6423 | +0.007 |
| | 0.5812 | 0.3208 | 0.3238 | +0.009 |
| | 0.3597 | 0.09754 | 0.09833 | +0.008 |
| 27° | 1.228 | 1.0216 | 1.022 | +0.0004 |
| | 0.974 | 0.5737 | 0.5746 | +0.0015 |
| | 0.7384 | 0.2881 | 0.2887 | +0.002 |
| | 0.4137 | 0.06946 | 0.06842 | −0.015 |
| | 0.3702 | 0.05224 | 0.05188 | −0.007 |

While few published records exist of discharges over notches having angles less than 90 deg. (though formulas have been suggested for these smaller angles, as mentioned later), experiments by Thomson,[4] Barr,[5] and Gaskell[6] on 90-deg. notches afford experimental results by which the proposed new formula may be tested. The comparison of the experimental and calculated discharges is given in Table 2.

TABLE 2 DISCHARGE CALCULATED BY THE FORMULA $Q = 2.415 \tan\left(\frac{\theta + 1.5°}{2}\right) H^{2.485}$ COMPARED WITH TESTS ON 90-DEG. NOTCH BY THOMSON, BARR, AND GASKELL

| | Head, ft. | Test figure | $Q$, ft. per sec. by proposed formula | By 90-deg. Cone formula |
|---|---|---|---|---|
| Thomson | 0.5833 | 0.6615 | 0.6495 | 0.6531 |
| | 0.5000 | 0.448 | 0.4428 | 0.4457 |
| | 0.4167 | 0.2845 | 0.2815 | 0.2835 |
| | 0.3333 | 0.1636 | 0.1616 | 0.163 |
| | 0.250 | 0.0796 | 0.07905 | 0.07984 |
| | 0.1667 | 0.0291 | 0.02888 | 0.0292 |
| Barr | 0.8333 | 1.578 | 1.5745 | 1.581 |
| | 0.75 | 1.215 | 1.218 | 1.224 |
| | 0.667 | 0.901 | 0.9054 | 0.9102 |
| | 0.5833 | 0.651 | 0.6495 | 0.6531 |
| | 0.5000 | 0.444 | 0.4428 | 0.4457 |
| | 0.4167 | 0.2825 | 0.2815 | 0.2835 |
| | 0.3333 | 0.1625 | 0.1616 | 0.163 |
| | 0.2500 | 0.0797 | 0.07905 | 0.07984 |
| | 0.1667 | 0.02925 | 0.02888 | 0.0292 |
| Gaskell | 0.7475 | 1.204 | 1.2025 | 1.208 |
| | 0.8764 | 1.79 | 1.786 | 1.793 |
| | 0.959 | 2.24 | 2.234 | 2.241 |
| | 1.023 | 2.626 | 2.621 | 2.63 |
| | 0.9935 | 2.443 | 2.438 | 2.446 |
| | 0.915 | 1.993 | 1.99 | 1.997 |
| | 0.809 | 1.465 | 1.463 | 1.47 |

After making extensive tests on sharp-edged notches of angles of 120, 90, 60, 30 deg., and 28 deg. 4 min., V. M. Cone[7] obtained the following formulas:

[1] Assoc-Mem., Institution of Mechanical Engineers.
[2] Trans. A.S.M.E., vol. 48 (1926), p. 939.
[3] Ibid., p. 956.
[4] *Civil Engineer and Architects' Journal*, Nov., 1858, Dec., 1861, and April, 1863.
[5] *Engineering*, April 8 and 15, 1910.
[6] *Proc. Inst. C. E.*, vol. 197 (1913–14), p. 258.
[7] *Journal of Agricultural Research*, vol. 5, no. 23, March 6, 1916. (U. S. Dept. of Agriculture.)

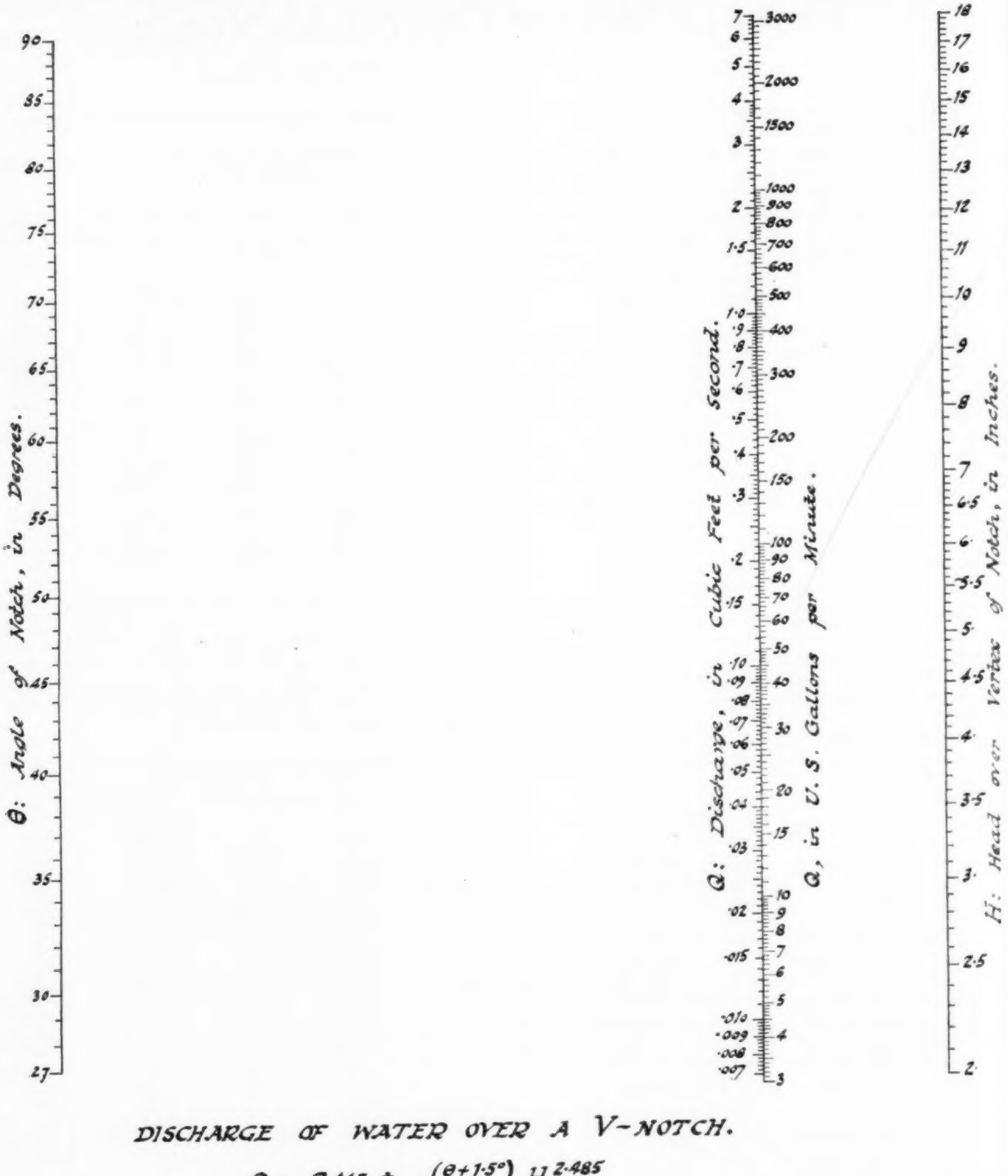


Fig. 1 Alignment Chart for Discharge Over V-Notches

| Angle | Formula |
|---|---|
| 120° | $Q = 4.400\ H^{2.4870}$ |
| 90° | $Q = 2.487\ H^{2.4805}$ |
| 60° | $Q = 1.446\ H^{2.4705}$ |
| 30° | $Q = 0.6848\ H^{2.4476}$ |
| 28°4′ | $Q = 0.6405\ H^{2.4448}$ |

and gives the following general formula for all these notches up to and including 90 deg.

$$Q = (0.025 + 2.462\ S)H^{\left(2.5 - \frac{0.0195}{S^{0.75}}\right)}$$

where $Q$ = cubic feet per second
$S$ = slope of sides, expressed decimally, and
$H$ = head in feet.

Cone found that notches of 120 deg. were impracticable for general use, as the nappe adhered to the edge for about $^1/_{12}$ ft. at the upper portion, although the notch was only $^1/_{32}$ in. thick. (Rowell[8] also mentions this, and recommends, instead of a wide-angle notch, several 90-deg. notches spaced so that there is no interference of flow. For non-interference he recommends that the notches be spaced apart a distance equal to seven times the maximum head.)

A comparison of the author's proposed general formula with Cone's 90-deg. formula is seen in Table 2.

Arranged for certain angles, the proposed formula becomes:

| Angle | Formula |
|---|---|
| 90° | $Q = 2.48\ H^{2.485}$ |
| 75° | $Q = 1.904\ H^{2.485}$ |
| 60° | $Q = 1.437\ H^{2.485}$ |
| 45° | $Q = 1.037\ H^{2.485}$ |
| 30° | $Q = 0.681\ H^{2.485}$ |

and a comparison of these formulas for 60 deg. and 30 deg. with the Cone formulas for the same angles is found in Table 3.

TABLE 3 COMPARISON OF FORMULAS FOR ANGLES OF 60 DEG. AND 30 DEG.

| | Head in feet | $Q$ (proposed formula) | $Q$ (Cone formula) |
|---|---|---|---|
| 60° | 1.25 | 2.502 | 2.51 |
| | 1.0 | 1.436 | 1.446 |
| | 0.75 | 0.706 | 0.714 |
| | 0.50 | 0.2567 | 0.261 |
| | 0.25 | 0.0458 | 0.04706 |
| 30° | 1.25 | 1.186 | 1.182 |
| | 1.0 | 0.681 | 0.6848 |
| | 0.75 | 0.3349 | 0.3401 |
| | 0.5 | 0.1217 | 0.1255 |
| | 0.25 | 0.02172 | 0.0230 |

Gourley and Crimp[9] give the formula, $Q = 2.48\ nH^{2.47}$, where $n$ is the tangent of half the angle of the notch. It will be found that the proposed formula gives results which, for the smaller angles, agree somewhat more closely with the observations than does this formula.

Barnes's[10] formulas,

$Q = 2.48\ H^{2.48}$ for 90 deg., and
$Q = 1.244\ H^{2.48}$ for 54 deg.

give results which are in close agreement with those obtained by the proposed formula when applied to these angles.

The experiments on which the formula is based were carried out on a sharp-edged notch, beveled off to $^1/_{32}$ in. in thickness, the upstream edge being square, in a tank so proportioned that the velocity of approach was negligible.

In a paper summarizing the work on the V-notch, it may not be out of place to state the general conditions necessary for satisfactorily measuring the flow by this method.

The edge should be of metal, $^1/_{16}$ in. thick, and square on the upstream edge; the plate should be set in a vertical plane and have its upstream face quite smooth.

(Barr found that coating the upstream face of the weir with coarse emery increased the discharge 2.4 per cent at 3 in. head, over that of a weir with a plain surface.)

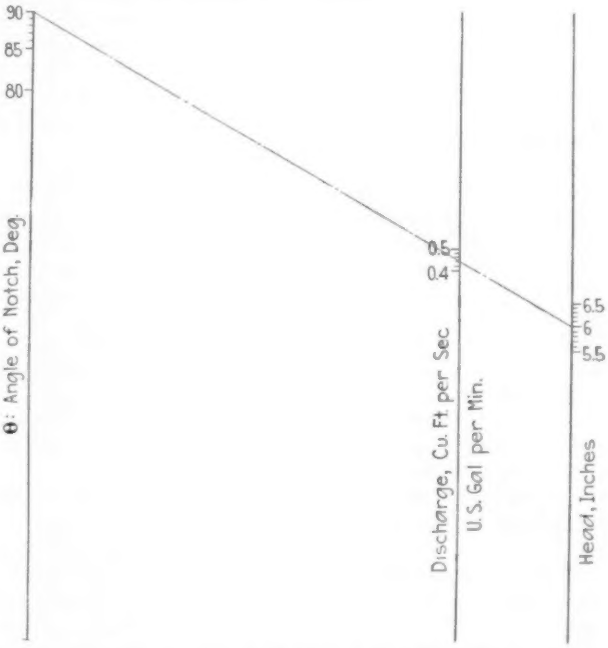


FIG. 2 SHOWING CONNECTOR LINE TO BE USED WITH CHART OF FIG. 1, AND GIVING AN EXAMPLE OF ITS USE

The width of channel should be such that the velocity of the water approaching the notch is not greater than 0.5 ft. per sec. The water should be stilled by means of suitable baffles. The width of the channel should be eight times the head for non-interference with the flow. (Reducing the width of the channel has the effect of increasing the flow by reducing the contraction at the sides of the notch.) The channel floor on the upstream side should be below the vertex a distance equal to three or four times the head. (Barr.)

Cone recommends measuring the head at a point at least either $4H$ upstream of weir or $2H$ to the side of the end of the crest.

Downstream, the level of the water should not rise above the vertex.

Where the velocity of approach exceeds 0.5 ft. per sec., Barnes suggests a correction for the head by adding to the observed head an amount equal to 0.01 $u$, where $u$ is the mean velocity of the water in the approach channel in feet per second.

Further tests on notches of small angles are desired for checking purposes, but it is believed that the proposed formula will prove useful within the range of angles specified. An alignment chart from which discharges may readily be read off in cubic feet per second or U. S. gallons per minute is given in Fig. 1, and an example of its use in Fig. 2.

[8] *Engineering*, May 2, 1913, p. 589.
[9] Proc. Inst. C. E., vol. 200 (1915), p. 388.
[10] "Hydraulic Flow Reviewed," Spon, London, 1916.

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# Progress in the Iron and Steel Industry

## Contributed by the Iron and Steel Division

Executive Committee: F. C. Biggert, Jr., W. W. Macon, C. S. Robinson, Geo. T. Snyder

THE year 1927 was one of unusual achievements in the American iron and steel industry, among which two have attracted particular attention. The first was the manufacture of large seamless tubing the foundation for which was laid in the preceding year. It was during the current year, however, that the success of the undertaking was proved. The reasons for undertaking it are well known. With an increase in the depth of wells, complaints as to the strength of pipe then used came from the oil country, with an insistent demand for large-size, heavy-walled seamless tubing.

### Manufacture of Large Seamless Tubing

Three companies have so far replied to this demand. One of these installed a German pilger mill, another provided both the German pilger and an American automatic mill, while a third limited its equipment to an American mill only. In all of these cases there was at first considerable doubt as to the ability to pierce billets of the size required for these machines. It was found ultimately that not only was there no trouble in regard to piercing, but that even rolled billets proved to be unnecessary and round ingots could be used as the raw material for the tubes. There are still certain mechanical problems requiring attention, but the success of the large seamless-tube mill in America has been decidedly established. As a matter of fact, greater production has been obtained in America from German mills than has ever been obtained in Germany.

### Continuous Sheet Rolling

The other development which has attracted special attention is continuous steel-sheet rolling. This does not belong entirely to the current year, as the installations at Ashland, Ky., and at Butler, Pa., were substantially completed late in 1926. Such was the promise of these applications of continuous rolling of sheets, however, that several other mills of the same character have since been laid down, and some of them have been put into operation. Among these may be mentioned the mills of the Laclede Steel Co. at Alton, Ill., the Weirton Steel Co. at Weirton, W. Va., the Trumbull Steel Co. at Warren, Ohio, and the American Sheet & Tin Plate Co. at Gary, Ind.

The introduction of continuous sheet rolling has been accompanied by further development of the four-high mill and the use of roller bearings in the big rolls, thus further familiarizing the steel industry with anti-friction bearings in their larger aspects.

These two developments among others served to direct increased attention toward research among tonnage steel makers. To mention only the more prominent units, the Bethlehem Steel Co. had already segregated research and development work into a special department in 1926. This year the United States Steel Corporation organized a research department and has given it an unusually high standing by making it report directly to the Finance Committee, which is the highest governing body of the corporation. George Gordon Crawford, president of the Tennessee Coal, Iron & Railroad Co., and Prof. John Johnston, of Yale University, have been placed in actual management of the new organization, while to the committee deciding on the program of research have been attracted men of such prominence as Frank B. Jewett, vice-president of the American Telephone & Telegraph Co., and Professor Millikan of the Norman Bridge Laboratory, University of California.

Throughout the year the steel industry has been permeated with a certain feeling of unrest and search for economies. The amount of business done by the mills has been of almost record capacity, but prices obtained for the products have been comparatively low, and the general feeling has been that profits were not commensurate with the unusual volume of business. It has been felt, therefore, that the greatest attention to costs must continue without relaxation, to insure profitable operation in coming years.

### Mill Drives

Steam as a means for driving the larger mills continued to lose ground. Among the outstanding electrifications of blooming-mill drive may be mentioned the installation of a 4000-hp. reversing motor at the plant of the Donner Steel Co. in Buffalo. A similar installation has been made by the Bourne-Fuller Co. at its Upson plant, while the Colorado Fuel & Iron Co. has put through an unusually ambitious project of electrification. In all these cases it is claimed that a better product is obtained at a lower cost. In the case of the Bourne-Fuller installation with the engine drive a maximum mill speed of 175 r.p.m. was obtained, and a speed of only 140 r.p.m. with a motor drive. It is not expected that as large maximum production will be obtainable from the electrified mill as before, but this is not considered important in view of mill and market factors modifying demands on the mill.

The progress made by powdered-fuel firing in central stations is making its way into the steel-mill field as well. At the Pueblo Works of the Colorado Fuel & Iron Co., powdered coal is used in the power plant. At the Central Iron & Steel Co. in Harrisburg, Pa., however, it is used in the heating furnaces of the plate mills. At first a unit pulverizer was installed, but later it was discarded and a central pulverizing plant is now used.

### Rolling Mills

The size and capacity of modern mills are well illustrated by performance at the works of the Lukens Steel Co., Coatesville, Pa., where steel ingots weighing 63,000 lb. each have been converted into slabs on the 206-in. plate mill. This is believed to be a record for size of ingots rolled. According to *The Iron Age* for May 12, 1927, the ingot was rolled into a slab 130 in. wide, 200 in. long, and $8^3/_4$ in. thick. Each of these slabs is used to make a "flywheel" blank $8^3/_4$ in. thick and 121 in. in diameter, the blank being cut from the slab by means of a portable automatic oxyacetylene cutting machine. The blanks are to be used in making herringbone-gear speed-reduction units.

A new structural mill at the Homestead Works of the Carnegie Steel Co. has been completed. It includes a blooming mill of 54-in. size, claimed to be the largest blooming mill in existence. Another feature is that it is to roll the new wide-flange Carnegie beams. Only two operators will control the main or auxiliary drives of this blooming mill. One man using a single master switch is capable of setting the three screwdowns on the roughing and intermediary mills. They automatically stop at predetermined settings by means of a specially designed limit switch, and secure the proper speed relations between the motors driving the main and edging stands for any condition of draft. This man controls several other operations, thirteen in all, during the rolling of each beam, a fact which is a good illustration of

the complexity of the apparatus used and the resulting amazing simplicity and extent of control in operation.

In the past year the so-called Neuves-Maisons process for the heat treatment of steel rails has become known. This consists of an intermittent quenching of the head of the rail in a definite quantity of cold water, this quantity depending on the weight of the rail. It is claimed that this treatment increases the tensile strength and also extends the hardening effect beyond the depth of normal wear.

### The Foundry Field

In the foundry field one of the interesting developments has been the application of hot blast to the cupola (H. K. Viall, *The Iron Age*, Oct. 20, 1927). In this case a standard cupola is used with only an upper wind box added below the charging floor. Carbon monoxide is drawn from the gases of combustion and used to preheat the air. Two years of operation have shown that combustion in the hot-blast cupola is more complete than in the cold-blast. Certain economies due to this more perfect combustion appear to have been established.

Further effort is being made in foundries to simplify and cheapen production, this being a more vital matter for foundrymen than ever before as castings today are in competition with forgings, stampings, automatic-machine products, and, finally, welded parts. In some directions castings have already lost out to welding. The latter has successfully replaced castings, for example, in large generators, parts of machine tools, etc. The foundry is meeting this situation in two ways. One is by permanent-mold casting, which has been applied, for example, to the making of Holley carburetors; the other is the employment of conveying devices. An interesting example of this latter class is the continuous unit for the manufacture of small gray-iron castings installed at the Elmira Foundry Co., Elmira, N. Y. (*The Iron Age*, Aug. 18, 1927.)

This report is only a general survey of the most important developments of the year, and no attempt has been made to cover progress in detail. This has been made necessary by the fact that the new Division is only just completing its organization.

Roy C. Brett,
*Organizing Chairman.*

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# Developments in 4-High Rolling Mills

## The Rolling of Wide and Thin Material; Early Mills and Experimental Designs; Technical Features of the Mills; Capacity and Power Consumption

By F. C. BIGGERT, JR.,[1] PITTSBURGH, PA.

UNTIL somewhat over a year ago progress in the rolling of strip steel had practically come to a standstill. The existing mills had succeeded in hot-rolling strip up to about 24 in. wide by 12 gage, and narrower widths as thin as 16 or 28 gage. Some material may have been made thinner than 12 gage in widths approaching 24 in., but I believe that the widths and thicknesses stated above represent the best commercial accomplishments of the time.

If wider material was to be rolled, it was evident that fundamental changes in mill construction must be made since increasing roll diameters, with the inevitable increase in neck friction which they imply, had about reached the practical limit.

The use of roller bearings was naturally considered, but no bearing could be designed which would support the required load and be small enough to assemble in the 2-high mills then in use.

We had built the 206-in. plate mill at Lukens Steel Company, and in it we used the 4-high mill, not so much to reduce power consumption as to limit the size of the chilled working rolls to dimensions within the facilities of chilled-roll makers. This mill had been successful and had demonstrated the possibilities of the 4-high type as a means of producing wide and relatively thin material of exceptionally accurate gage. That is to say, this plate mill had been found capable of rolling plates as thin as $^3/_8$-in. in widths up to 16 ft. and having a uniformity of gage from edge to center quite as good as had previously been produced in ordinary widths. The life and behavior of the rolls were remarkably good. No spalling occurred, and the medium-carbon-steel backing rolls maintained their shape well.

Some difficulty with fire-cracking of the chilled rolls occurred due to the very large ingots used and the slow and heavy drafts in the early passes, but it was evident that with slabs such as would be used in strip mills, this would not be serious.

### Difficulty in Rolling Wide and Thin Material

Considering the possibilities of wider strips in the light of this plate-mill experience, we concluded that the same type of mill offered the means required. There were difficulties, however.

In rolling thin material, the power cost becomes a matter of importance, and while the 4-high mill is inherently more efficient than the older types, yet, if run on ordinary bearings, the power per ton would still be rather high.

A large and expensive installation rolling thin material must deliver at high speed if tonnage, commensurate with the installation cost, is to be obtained, and with ordinary bearings, this would involve excessive heating.

On thin material a mill must maintain its setting much more accurately than in ordinary rolling. The wear of ordinary bearings, which, in thick rolling, is of small importance, becomes vitally important when the thickness approaches $^1/_{16}$ in.

All these difficulties could be overcome if roller bearings could be obtained capable of sustaining the loads involved.

### Early 4-High Mills

Our engineers had developed the requirements thus far and had made some inquiries indicating that suitable bearings could be obtained, when we were called to the plant of Rome Brass & Copper Company, Rome, N. Y., to advise with that company as to means of improving their practice in producing sheet copper.

Having studied copper-rolling practice, with which we had previously been entirely unfamiliar, we concluded that the 4-high roller-bearing mill met the requirements completely.

The question of roller-bearing design was discussed with Mr. W. Messinger of Philadelphia, and having determined sizes which, upon rather meager data, appeared to meet the requirements, a mill was built. It has proved satisfactory.

This mill had scarcely started and was still in a highly experimental state when Columbia Steel Company came into the market for a steel strip mill to roll 30-in. wide material down to 12 gage; afterward changed to 36 in. wide by 12 gage.

Here was a chance to try out the 4-high principle in a big way, but we were poorly prepared, having still only imperfect data on which to base designs. We decided to make a clean breast of the matter and see if Columbia would go along with us in a large-scale experiment. The allurements were great and we convinced them that the experiment was worth making. They installed a universal roughing mill followed by four stands of 4-high hot mills arranged in tandem and five stands of similar cold mills. The E. W. Bliss Company supplied the cold mills.

Generally speaking, these mills have been successful, although bearing troubles have been encountered, to some extent, on the hot mills. This is primarily due to rolling 14- to 16-gage material, in which case the steel is too cool when it is delivered to the finishing train. A universal mill is not fast enough for a strip-mill rougher where the gage to be finished is thinner than 12. Sheets as wide as 36 in. and down to 16 gage are being produced on the mill, but changes will be required before this can be done satisfactorily. As the mill now stands, 14 gage by 36 in. wide is its commercial limit.

Before the Columbia mill design was well started, Weirton Steel Company decided to install a tandem train of 9 hot mills and two 5-stand trains of cold mills to roll 48 in. wide. The experiment was getting too hot for us and we insisted that reliable data be obtained before proceeding with designs.

Pressure-measuring devices and also devices for measuring neck friction in ordinary strip mills were deviced, built, and applied, and from these devices we obtained remarkably consistent data upon which to base both bearing loads and motor powers.

The Weirton hot mills have now been in operation for some three months, and so far neither bearing nor roll troubles have appeared. Widths up to 38-in. have been hot-rolled to 16 gage commercially, and 36 in. wide 17 gage has been produced experimentally.

Other steel companies have also taken up this new type of mill. Lukens Steel Company has an 84-in. plate mill built among the first. Trumbull Steel Company has remodeled its 16-in. wide mill using five stands of 4-high in its finishing train and have thus increased its capacity from 18-in. to 30-in. widths. A

[1] President, United Engineering and Foundry Co., Pittsburgh, Pa. Mem. A.S.M.E.

Presented at a meeting of the Iron and Steel Division, Youngstown, Ohio, Nov. 10, 1927, of The American Society of Mechanical Engineers.

further change in the roughing train will permit rolling 36 in. Youngstown Sheet & Tube Company has a single stand with 72-in. roll. American Sheet & Tin Plate Company is installing six stands which will be referred to later, and there are numerous others. Some 80 stands of 4-high roller-bearing mills, hot and cold, have been contracted for within a period of less than two years, indicating the remarkable interest aroused by the development.

### Hot and Cold Rolling

Just what will be the outcome of this development is difficult to say. There are the two distinct fields of hot and cold rolling to which the mill is eminently suited. In hot rolling, it is safe to say that 16 gage is near the practical limit, although American Sheet & Tin Plate Company proposes to go to 18 gage by 28 in. wide, and will doubtless accomplish this.

Leaving the hot mill at 16 or 18 gage, we have the choice of further reduction through cold strip mills or by packs on ordinary sheet or tin mills.

Both of these methods probably have their field of usefulness. For very light gages, particularly tin plate, it may be that the hot pack will prove most economical. This is the method being tried out by American Sheet & Tin Plate Company, and it will surely reduce the cost as compared with present-day practice.

Down to 24 or 26 gage, particularly for full-finished and similar bright stock, there seems to be little doubt that the cold-strip process is best. The operation of these cold mills is just beginning. At present we do not know either the minimum thickness or the maximum speed which may be commercially obtained, and until these factors are determined, it will be impossible to decide which process will survive.

Another factor of importance is the question of coating. We are not yet sure that the cold-rolled material will take a satisfactory coat of either tin or spelter, but the probability is that by suitable preparatory processing such coatings may be applied.

Where feasible, the cold-strip process seems to have great advantages. Labor is much reduced; crop losses are almost negligible; pickle cost is from one-half to one-fourth of that for the pack process; frequently it will be advantageous to have the finished material in strip form rather than in sheets, and the remarkable accuracy of gage should increase the demand for strips.

On the whole, we are disposed to believe that reduction by the cold process will ultimately prove to be the economical method of producing the large-tonnage gages, perhaps including tin plate.

The accuracy of rolling with these mills is quite remarkable. It is not difficult to hot-roll strips 259 ft. long 30 in. wide and $^1/_{16}$ in. thick with edge-to-center and end-to-end variations within 0.003 in. At Weirton this degree of accuracy has been exceeded in regular production. I have personally callipered coils 36 in. wide by 0.080 in. thick which showed only 0.002-in. edge-to-center variation. But this practice has been abandoned and about 0.004-in. fullness is being allowed on account of the difficulty of handling the more accurate coils in the cold mills. There is much less difficulty in cold rolling if the metal has an appreciable fullness at the center.

The practice in the hot mills is to start with a 3-in. thick slab regardless of the finished gage, and, with suitable edging equipment, an excellent edge is produced on the finished strip. The edges are somewhat rounded but very straight and smooth, so that even for the most exacting sheet requirements it will only be necessary to side-trim about $^1/_8$-in. The length of strip is so great (200 to 400 ft. hot-rolled and 300 to 1200 ft. after cold rolling) that end crop loss becomes almost entirely negligible.

### Capacity

A hot mill arranged like that at Weirton can easily produce 40 long tons per hour of 30-in. wide 16-gage material. The theoretical discharge of this material at the usual finishing speed of 800 ft. per min. is 135 long tons per hour, so that placing the average production at 40 tons is doubtless conservative.

The possibilities of the cold mills are not so well established, but it is fairly well proved that a delivery speed of 200 ft. per min. can be maintained and that a reduction of 60 per cent in thickness can be obtained in a 4-stand train.

If, then, we start with 16 gage 30 in. wide, we may reduce to about 24 gage which, for 30-in. wide material delivering at only 150 ft. per min., amounts to a theoretical discharge of 10 tons per hour. Cold mills can be run on a very high production factor on account of the great length of entering piece, so it seems very safe to say that such a train should produce 8 tons per hour of this material. This rate of production has been exceeded for short periods, and seems a very conservative estimate, especially when we remember that there is good probability of attaining speeds higher than that assumed.

### Power Consumption

Power consumed per ton of product has not yet been well established, because all the mills now in operation are running intermittently and under adverse operating conditions, but such data as are available indicate a power requirement about one-half that used in ordinary strip mills for corresponding sizes. On 16-gage material reduced from 3-in. slabs, we believe 80 kw-hr. per ton is a safe figure for hot rolling. Reducing 60 per cent cold from hot-rolled material of 12 to 16 gage, will require about 30 kw-hr. per ton.

The ordinary production of sheet mills is one short ton per hour per mill. On 24-gage sheets, we may allow one long ton per hour as a monthly average per mill.

On this basis and that of the figures previously quoted for hot and cold strip mills, we may assume that one hot-strip mill, such as those at Weirton or Trumbull, with enough cold mills to reduce its product from 16 gage to 24 gage, will be equivalent to 40 sheet mills.

But the sheet mills require sheet bar as their raw material, whereas the strip mill requires slabs which come direct from the blooming mill.

To make a true comparison, we must, therefore, place one hot strip mill with its complement of cold mills against 40 sheet mills and a very good sheet bar mill. The two plants will cost about equal amounts and should produce equal tonnages.

### Tin-Plate Mills

The problem of producing tin-plate and sheets of corresponding thickness by the new methods is particularly interesting, and the American Sheet & Tin Plate Company is to be congratulated upon the steps it has taken in this direction.

Their scheme is to reduce to about 18 gage in a 4-high strip mill, and match, double, and finish on their existing tin-plate mills. The entire roughing operation is thus transferred to the high-production strip mill; the scrap loss should be reduced because of the very accurate dimensions of the pack at the doubling point, and finishing mills may be run at a higher rate because of the reduced roll heating.

Incidentally, this company has burned no bridges since its hot strip mill will be equally well adapted to roughing for cold mills, should it be later found economical to finish cold.

So much for the historical and economic side of the development. From an engineering standpoint, the following may be of interest:

### Use of Roller Bearings

We have used roller bearings of the parallel-roller type on

the backing rolls, because we believed that this type was most suitable to the extreme loads to be carried. We do not know that this is true, but it is to be remembered that in starting this development, we were working in the dark. Speed, load, and available space for assembly considered, these bearings carry several times the load of any roller bearing previously used. Not only is the duty required greater than has been previously demanded of bearings of equal dimensions, but also the manufacture of such sizes had been, by no means, standardized. On this account, we doubted the applicability of formulas of all roller-bearing manufacturers, and were forced to rely largely upon our own analysis in determining both sizes and type of bearings.

The results of practice so far have been fairly satisfactory. On cold mills we have had no trouble, as the loads may be calculated with fair accuracy. Some of the earlier hot mills have given trouble which has been traced to two important sources: first, the excessive loads due to the rolling cold steel, and second, the unavoidable stresses due to cobbles, broken rolls, and similar accidents.

The increase in rolling pressure due to cold steel may easily double the load on the bearings. For instance, at Weirton, measurements taken at the beginning of a run when the first few slabs were not well heated, as compared with corresponding measurements a few minutes later, showed pressures in the ratio of 4 to $2^1/_2$, and the cold slabs were only about 100 to 200 deg. fahr. low in temperature.

There is no means for measuring the momentary pressures due to accidents, but it is obvious that they will increase the demands upon the bearings.

Neither of these occurrences causes immediate failure of bearings, but their repetition may ultimately result in failure, and good safety factors, combined with good heating and good mill practice, are necessary to obtain good bearing performance.

Working-roll bearings used so far have been of ordinary mill-type bronze. The loads on these bearings are theoretically very small, and when the rolls are properly aligned, they are practically quite small. Since specially good alignment is necessary if good rolling is expected, regardless of bearings, and since the rolls, once properly aligned, have little tendency to change their position, there is little need of more refined equipment.

Roller bearings have been suggested for the working rolls, but the small advantage, difficulty of assembly, cost, and almost certainty of destruction every time a roll breaks, have prevented our recommending them.

### Size of Rolls

Sizes of working rolls have been determined from the size of coupling necessary to transmit the required torque. We have based our designs upon elaborate full-size tests to destruction.

Backing rolls have been made of sufficient diameter to accommodate the required bearings, as this usually gives a roll of ample stiffness.

An interesting development in regard to working-roll diameter is that it has no appreciable effect upon the power consumption of the mills. This is, of course, contrary to all previous conceptions, but tests over a wide range of diameters have shown that for like reductions, the power per ton is almost exactly constant.

Of course, the rolling pressure increases with increasing roll diameter, and with ordinary bronze bearings, the larger necks absorb more power. This is the reason that in ordinary mills, the power per ton increases with increasing roll diameters. The friction coefficient of roller bearings is in the order of 0.0009, and consequently the power absorbed by necks is so small that it has almost no effect upon the total power consumption.

This is important since it removes the principal argument for minimum-diameter working roll, and permits the use of rolls large enough to stand severe accidental stresses.

### Motion of Rolls

Another prevalent idea that has been disproved is that the rolls of a mill tend to move out of the housings in the direction of the movement of the material.

The fact is that with equal diameters of top and bottom working roll, there is no tendency to move with the piece, but a back pull toward the entering side just sufficient to pull the material into the mill.

If the material is carried on roller tables moving at the same speed as the mill, this pull is zero and in no case can it be more than the friction due to the weight of the material.

This may be demonstrated by putting exactly equal rolls in any 2-high or 4-high mill and examining the lost motion of the chucks. They will be found usually to bear against the housing post on the entering side and may be displaced by a very slight pressure applied between chuck and housing.

This is not true when the rolls are of unequal diameter nor in the case of a 3-high plate mill where the middle roll is friction-driven from top or bottom rolls.

In the 4-high mills, it has been found advantageous to set the working rolls a small distance off center from the backing rolls. Usually this has been toward the delivery side, although they seem to work about equally well if offset toward the entry side.

We do not know any good reason for this displacement unless it be that it definitely establishes the direction in which the rolls will settle when the piece enters. If they are exactly on center, small unavoidable differences in diameter or other inaccuracies, may cause one end to settle backward and the other forward, whereas by giving a definite offset, they must settle uniformly. Whatever the reason, mill operators find it convenient to offset the rolls as much as $^1/_4$ in. and obtain more uniform results by so doing.

### Composition of Rolls

In the hot mills, after experimenting with rolls of various composition, it appears that fairly high-carbon alloy-steel backing rolls and chilled alloy-iron working rolls will give the best results, although ordinary mild-chill working rolls have given good service where it has been possible to finish at proper temperature.

The cold mills have worked well with medium-carbon-steel backing rolls and hardened-steel working rolls. Ordinary chilled backing rolls have also given good service, and on cold mills it appears that any reasonably hard roll will serve for the backing rolls.

On both hot and cold mills, the experience available is not sufficient to warrant a definite statement as to the best combinations of working and backing rolls, but it is evident that rolls can be made which will give commercially acceptable service.

## Discussion

Lloyd Jones.[2] The application of mills with backed-up rolls is not new, and has been practiced throughout the metal-rolling industry continuously in various forms and shapes for over 60 years. There are approximately five types of backed-up mills, of which the 3-high is in most general use, with the 4-roll and the cluster types following in the order named.

For the rolling of sheets and strips, the 4-roll type and the cluster type are better adapted than 3-roll type, and will eventually supersede it altogether. As to the relative merits of the two

[2] E. W. Bliss and Co., Salem, Ohio.

outstanding types of backed-up mills, namely the 4-roll and cluster types, their merits may be presented as follows:

*Four-Roll Type*

1 Shorter distance from the edge of the housing to the center of the mill

2 Smaller number of rolls.

*Cluster Type*

1 No bearings for holding the work rolls in alignment are necessary

2 The working roll cannot wear out of alignment, hence the cluster-mill operator does not experience the difficulty which the 4-roll operator experiences, due to the terrific end thrust of the working rolls when they become slightly crossed

3 The working rolls can be more quickly changed, as there are no bearings to handle

4 The working rolls automatically align themselves when placed in the mill by coming in contact with the two supporting rolls, eliminating the human element in lining up the mill

5 The contact pressure between the work rolls and the supporting rolls is approximately 30 per cent less per inch of face on the cluster mill, as compared to the 4-roll mill

6 The working roll is supported in both directions of force, and hence small diameter rolls can be used to accomplish the same work

7 With equal diameter of working roll, and with the ratio of backing-up roll to the working roll approximately 2 to 1, which is the general ratio, the cluster mill has approximately 40 per cent greater capacity.

There have been difficulties in holding the rolls in alignment on the 4-roll type. The brasses on the necks become worn, or the mill is not set in correct alignment, and the rolls quickly develop an end thrust which makes the changing of the roll-neck brasses necessary at frequent intervals. To overcome this tendency, the last 4-roll mill shipped to the American Sheet and Tin Plate Company was equipped with roller bearings on the working rolls as well as on the supporting rolls. This was possible because the mill was to be used for cold-rolling purposes, and the working rolls were made of hardened tool steel, which allowed a reduction of the neck diameter sufficient to install the bearings, and at the same time gave sufficient strength to prevent the neck from twisting off.

It is a question in our minds whether this can be successfully done when the mill is used for hot-rolling purposes, especially with rolls made of chilled iron. In this case we have to deal with a metal of low strength, and the torsional stresses would probably twist off the neck.

Another illustration having to do with supporting the rolls in both directions is found in the following experience: If a cobble takes place on the 4-roll mill, the working rolls are apt to break and fly out of the mill. On the cluster type of mill, there was an accident in which metal being rolled escaped the stripper, and passed around the working roll between the supporting rolls approximately six times before the mill was stopped. The only damage that occurred was that the working roll was marked and had to be taken out and redressed. No damage was done to the supporting rolls or to the roller bearings, and the six thicknesses of metal were reduced to the single thickness being rolled, the six laminations being actually welded together cold. This was a remarkable example of the enormous pressure which roller bearings will stand.

As regards the application of roller bearings to mills, this, like the backed-up-roll principle, is old as to the writer's knowledge, roller bearings on both 2-high mills and backed-up mills have been in actual use for probably 16 years in this country.

We have been applying roller bearings for the last three years on all types of mills, 4-high, cluster type, and also on the ordinary 2-high mills. Our experience so far with roller bearings has been excellent, as we have had no failures or replacements to date.

The construction of the 4-roll and cluster types of mills lend themselves ideally to the application of roller bearings. This is one of the reasons why mills of these types are rapidly coming into favor. The power saved by the use of the small diameter rolls is not as great as the power saved by the use of roller bearings. The roller-bearing application, however, is spreading to 2-high mills, and we have a number of them in operation at the present time.

With reference to the adjustment of rolls in the backed-up mills, there is no difference in the principles involved, and the only departure has been the application of electric power to the screw-downs in place of hand power. This, of course, is not new on plate mills, blooming mills, etc., but is new to the sheet and strip industry. In regard to the adjustment of the rolls as far as alignment is concerned, our practice is to build the mill so that the workman has nothing whatever to do with it.

In the cluster mill the working rolls align themselves. In our 4-roll mill for cold rolling we put roller bearings on work rolls and take away all adjustment features. For hot rolling, where we have difficulty applying roller bearings to the working rolls, we believe that the best solution to this problem will be the adoption of the cluster type of mill in place of the 4-roll mill. This will also solve several other difficulties present in the 4-roll mill which has up-to-date been generally used for hot rolling, namely (1) the alignment of the working rolls, (2) increasing the life of the supporting roll surface by from 30 to 50 per cent, (3) decreasing roller-bearing troubles now experienced, and (4) reducing work-roll breakage.

Another interesting feature about backed-up mills is that on account of the small arc of contact with the metal being rolled, the total bending load on the mill is considerably less. This cuts down the deflection or spring in the mill, and in many cases obviates the necessity for crowning the rolls. The practice of shaping the surface of the roll to deliver a sheet or strip within commercial tolerances has been common practice ever since the speaker has had anything to do with the steel business. When the first cluster mill was installed at Huntington in the early part of 1923, we assumed that it would be necessary to crown the working rolls and started that mill with the one roll straight and the other one crowned. The backing-up rolls were all straight cylinders. We soon found that we did not need as much crowning, and this has been gradually reduced.

This question of shaping the rolls is becoming of less importance every day, and our practice now is to ship the mills from our shops with rolls ground perfectly straight. Whether crowning of the rolls is necessary or not seems to depend a good deal upon the product which is rolled in the mill. With the use of roller bearings, which eliminates the heat produced by neck friction, the swelling of the rolls at their ends due to increased temperature is being eliminated, and this in turn also has a tendency to do away with the old practice of shaping the rolls.

It might be well at this time to touch slightly upon the historical phase. About 1913 there were eight cluster mills in operation, and one 4-roll mill. About 1916 the second 4-high mill was installed at Lukens Steel Company. From then there is a gap of approximately seven years, until 1923, and since then there has been a tremendous building of backed-up mills.

What caused this sudden revival of the backed-up mill?

During 1922, the Internationl Nickel Company, at its plant at Huntington, West Virginia, was making full-finished nickel and monel-metal sheets. In order to secure the desired surface it was

found necessary to grind, polish, and buff the sheet before sending it out to the trade. This was a slow and costly process.

In talking the matter over with their Dr. Thompson and Mr. Wotherspoon, the writer proposed cold rolling as a solution. We conducted some experiments and found that by reducing the thickness by cold working, we could secure a surface which would eliminate the grinding process. These experiments were conducted on the ordinary 2-high mill with strips approximately 18 in. wide.

To accomplish the same amount of reduction on sheets 36 in. on the ordinary 2-high cold-rolling sheet mill, of which there were several in the plant, the rolls being 26 in. in diameter, we found it would be necessary to make from 40 to 60 passes. The writer then proposed a mill of the backed-up principle, and we were all convinced that that was our only solution to the problem.

When it came to the choice of backed-up mill, there were two types. The writer was well acquainted with the 4-roll type built for Lukens Steel Company as all drawings for this mill, prior to being issued to the shops, had his signature of approval on them. He was also familiar with the cluster type of mill which had been operating since 1913. In studying over the advantages of the two types of mills at that time, his preference fell to the cluster type, and this type was installed at Huntington.

We quickly found that we could accomplish in 3 to 4 passes on this mill what took 40 or more passes on the regular 26-in. mill. This mill was visited by practically every sheet and strip manufacturer in the country, and many of the prominent sheet manufacturers sent sheets to Huntington to be cold-rolled.

This was really the starting of the modern strip method of rolling sheets, because it removed the limitations on the old hot- and cold-rolling strip practice, and allowed the adoption of this practice to widths wider than had been rolled, and further encroached upon the sheet trade.

Charles L. Huston.[3] When the World War broke out in 1914, and the United States in process of time was called upon for war supplies of all kinds, the demand for heavy steel plates for Scotch-marine boilers, and for wide and heavy plates for the modern type of locomotive became acute, plate mills were so busy with plates of ordinary size that they did not wish to risk breaking down their mills with this heavy work.

To meet this situation, the Lukens Iron and Steel Company (now Lukens Steel Company) decided to build a mill large enough to take care of all present and prospective demands. The customary 3-high plate mill was found to be inadequate because of the difficulty and risk involved in making and using the long chilled rolls of large diameter which would be required.

After a careful study of the field, an adaptation of the 4-high mill built by Julian Kennedy for the Carnegie Steel Company, about 1890, was given consideration.

This mill had been intended for rolling armor plate, but, for some reason, was found to be not quite satisfactory for this purpose, and was turned into a slabbing mill. It was built with working rolls of comparatively small diameter, these being driven directly from the reversing engines, through the pinions.

The possible explanation of the reported difficulties seemed to be that the large supporting roll, underneath the lower operating roll, would fail to reverse promptly when the driving engines reversed, because the weight of the lower operating roll, added to the weight of the large supporting roll and all resting upon the journals of the supporting or backing-up roll, resulted in an extra frictional resistance upon the journals of the supporting roll, which, added to the inertia of the heavy supporting roll when the motion of the mill was reversed, caused slippage between the working and supporting rolls and possibly wore little grooves or irregularities in the surface of the supporting roll, and these through irregular support of the working roll made objectionable marks on the surface of a finely finished rolled plate.

[3] Vice-President, Lukens Steel Co., Coatesville, Pa. Mem. A.S. M.E.

The simplest way of remedying this trouble seemed to be to provide a direct drive for the bottom or supporting roll, which, geared to the lower pinion, would, through a suitable friction device, be of sufficient power promptly to reverse the bottom supporting roll, and yet avoid conflict of speeds and possible breakage of the driving mechanism when the rolls, after some period of wear, might become changed in their relative diameters and therefore be of a ratio different from that of the pinions at the driving end.

The contract for building this mill on a cost-plus-percentage basis was given to the United Engineering and Foundry Company, Mr. F. C. Biggert, Jr., now President, being at that time Vice-President and Chief Engineer. Mr. Biggert, with his engineering staff, took special care in working out the designs and proportion, of this mill, which, being heavier than anything heretofore attempted, as it had to take care of very heavy as well as wide work, had to be of a new design throughout. Mr. Lloyd Jones, then with the United Engineering and Foundry Company, was given charge of working out the details of the mill in cooperation with the writer and the engineering staffs of the Lukens Steel Company and the United Engineering and Foundry Company.

The drive for the mill consisted of 46 by 70 in. diameter, 60 in. stroke, twin, tandem-compound, condensing, reversing engines geared two to one on the mill. The size of this engine was determined after some special tests had been made by Prof. Wm. Trinks of the Carnegie Institute of Technology, and has proved to be of just the right capacity.

This new type of mill did in practice all or more than was expected of it, as it has made very uniform gages, rolling plates 16 ft. wide down to $^3/_8$ in. gage, for the sides and crowns of locomotive boilers, with comparatively little difference in thickness between the edge and the center.

The cast-steel supporting rolls, 50 in. in diameter, furnished the strength and stiffness, while the chilled-iron working rolls, 34 in. in diameter, gave the desired finish, and were free from the spring and over-strain usually resulting from the customary type of mill. One of the features of this design is that the working rolls, which come into contact with the hot metal, and hence are subjected to heavy internal expansion strains, are freed from the burden of the transverse stress and, consequently, are less liable to breakage, while the large rolls, made of stronger material, are also not required to come into contact with the hot metal, and are free from consequent internal strains caused by the heating of the surface, and are in better condition thus to do their own part of the work of carrying the transverse bending stresses.

The size of the mill required a special design of housings, each housing being made in four parts, with suitably fitted joints strongly bolted together, and reaching across half way toward the opposite housing, thus forming the bridge for carrying the hydraulic counter-balancing mechanism and the powerful driving mechanism for the adjusting screws. The total height of the housing from the bottom of the bed plate to the top of the casing protecting the housing screws is practically 40 ft.

It is interesting to note that the main features of this mill, designed by Julian Kennedy nearly forty years ago, are now forming the basis, with suitable modifications, for the latest types of mills, for meeting the exactions of gage and finish now being so much sought after in light as well as heavy work.

R. J. Wean.[4] This discussion deals with the commercial aspect of 4-high and continuous mills. It is obvious that more

[4] Aetna Standard Engineering Co., Youngstown, Ohio.

thought and development has been put on the mechanical phase of these mills by Mr. Biggert and his company than has been given to the development of the market for the product made on this type of mill.

There is no question that steel in long lengths and in widths up to 42 in. can be rolled on hot mills of this kind, but when this product has been produced, it still remains in the form of hot strip steel and it is necessary to subject this to various finishing processes to impart the finished and physical properties required by the uses to which sheet steel is put. As these uses differ widely and are numerous, the sheet-steel industry is one of specialties.

The great diversity of uses, and the various modifications in treatment during the processes of manufacture required to adapt sheets to these uses make up a very long list of products. It is very unusual to have an extremely wide range of these various sheet grades made in one plant. Therefore, it cannot be expected that the operators of continuous 4-high mills can afford to finish this material into the wide ramification of grades required to serve the sheet industry.

The installation and operation of continuous 4-high mills have affected the sheet-steel market to such an extent that selling prices are much lower than they should be for either the sheet-steel producer or the producer of wide strip steel. They have been competing in the same market, whereas it appears as though they might serve each other to supply the same market on a non-competitive basis.

Would it not be better for the producer of wide strip steel to furnish the sheet-steel industry with material rolled down to 12, 14, or 16 gage in the form of hot strip steel and permit the experienced sheet-steel manufacturer to finish this material into the various grades required by the sheet consumers?

In this way there would be sufficient tonnage available for the wide-strip-steel operator to keep his mill in continuous operation and still make use of the existing sheet-steel finishing capacity in this country.

This same application can be made to the manufacturer of tin plate, as witnessed by the installation of one of these mills for the production of tin-mill breakdowns alone.

Surely the development of this market is worth considerable thought. The cooperation of the wide-strip producer and the sheet-steel producer would not only work out to the economic advantage of both, but to the entire steel industry as well, and most certainly to the stockholders who have invested their money in these companies.

# Destruction Test of a 66-In. Forged Steel Penstock Pipe

By JOHN L. COX,[1] PHILADELPHIA, PA.

*The section of pipe tested is representative of a portion of one section of the penstock of the Big Creek Power Plant No. 2, near Los Angeles, Calif., of the Southern California Edison Co., with the object of determining the elastic limit and ultimate strength, as well as the deformation and behavior under high pressure.*

*Details and specifications of the pipe section are given as well as a description of the test arrangements and measuring apparatus. The test is described and the results are given in tabular and graphic form.*

*The pipe reached its elastic limit at a pressure of 2150 lb. corresponding to a tangential stress of 25,000 lb. per sq. in. in the steel of the walls, the measured proportional limit of the steel at the ends being 24,500 lb. The pipe failed at a pressure of 5300 lb., which, by the approximation of the extended Birnie formula, would correspond to a fiber stress of 62,000 lb. per sq. in., compared with an actual tensile strength of 67,750 lb. The external expansion was 6 in. in diameter, or 8.3 per cent. The internal expansion was 6-3/8 in. in diameter or 9.63 per cent. The mean expansion of the wall was 8.96 per cent. The reduction in wall thickness at the mid-length of the pipe at the fracture was 3/16 in. or 6.25 per cent. The paper closes with a discussion of the results of the test.*

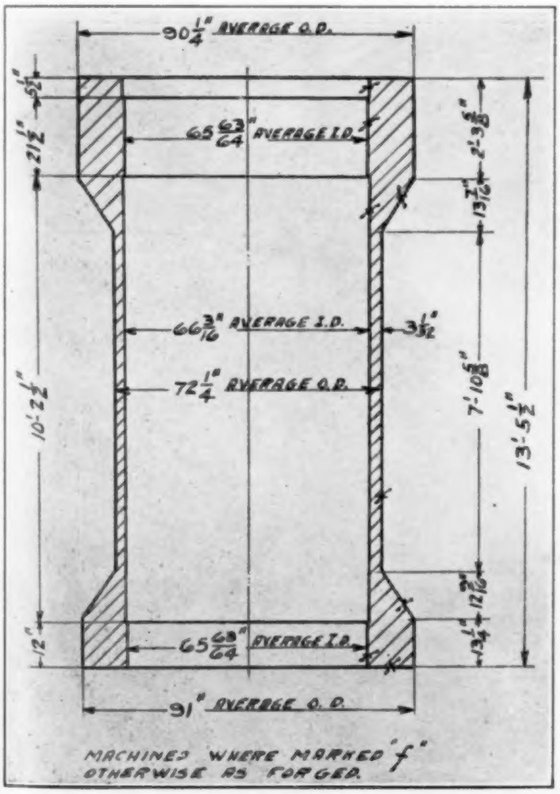

FIG. 1 SKETCH SHOWING DIMENSIONS OF THE PIPE BEFORE THE TEST

(Machined where marked "*f*;" otherwise as forged.)

### THE PROBLEM

THE Southern California Edison Company is building a high-head hydroelectric station at Big Creek Power Plant No. 2 near Fresno, California. At high water level the total head above the nozzles is 2419 ft., corresponding to a water pressure of 1050 lb. per sq. in.

The penstock consists of a single line of riveted or welded pipe running from the intake to a point where the head is 1644 ft., corresponding to a pressure of 715 lb. per sq. in. Below that point it is a 66-in. line 1682 ft. long, dividing into two 48-in. lines each 80 ft. long, subdividing again into four 34-in. lines each 60 ft. long, which run to the nozzles. The total length of the penstock is 6480 ft. of direct line, not including laterals.

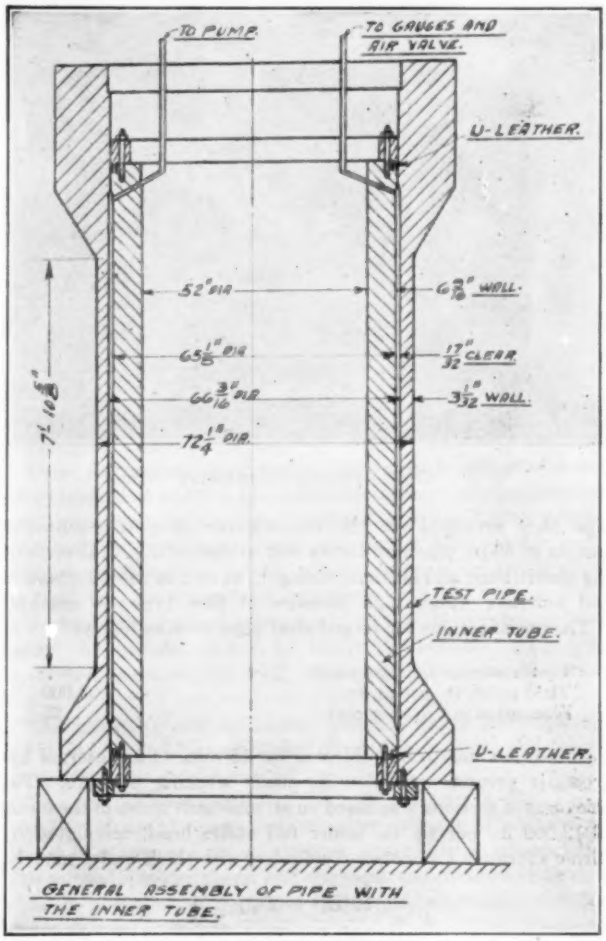


FIG. 2 GENERAL ASSEMBLY OF PIPE WITH THE INNER TUBE

Owing to the high head and to some experience with brittle pipe bursting without appreciable expansion, the company's en-

[1] The Midvale Company.

Presented at the Annual Meeting, New York, December 5 to 8, 1927, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

gineers specified for the higher-pressure section of the line (that above 715 lb. pressure) the use of forged-steel sections with integral coupling flanges, but before contracting for this type of

FIG. 3 FITTING UP THE PIPE

pipe they arranged for the manufacture of a representative section of 66-in. pipe and for its test to destruction to determine the elastic limit and ultimate strength, as well as the deformation and behavior under high pressure of this type of conduit.

The specifications for forged-steel pipe were as follows:

| | |
|---|---|
| Tensile strength, lb. per sq. in. | 62,000 |
| Yield point, lb. per sq. in. | 35,000 |
| Elongation in 2 in., per cent | 25 |

Each section was to be subjected for 15 min. to an internal hydrostatic pressure of twice its static working pressure. The thickness of sections was based on an allowable stress in the metal of 12,000 lb. per sq. in. under full static head, calculated by Birnie's formula for open-end cylinders with thick walls: namely,

$$P = \frac{10(D_1^2 - D_2^2)}{13D_1^2 + 7D_2^2} \times S$$

where $P$ = internal pressure in pounds per square inch
$D_1$ = outside diameter in inches
$D_2$ = inside diameter in inches, and
$S$ = fiber stress in pounds per square inch.

For reasons of economy the body of the test pipe was reduced in length to 8 ft., that being considered sufficiently long to avoid reinforcement of the mid-length by the end flanges—a view that later proved to be correct.

Fig. 1 shows the design adopted for this representative forging. The pipe had an average internal diameter of $66^3/_{16}$ in., an average wall thickness of $3^1/_{32}$ in. over a length of $94^5/_8$ in., and a heavy flange at each end.

## MANUFACTURE

To this design a forging was made from a 63-in. octagon ingot of acid open-hearth steel of the following composition:

| | |
|---|---|
| Carbon | 0.29 |
| Manganese | 0.51 |
| Phosphorus | 0.024 |
| Sulphur | 0.042 |
| Silicon | 0.21 |

After reheating, the ingot was cropped, punched, expanded, and forged under a 9000-ton hydraulic press, then lightly annealed. The average physical properties obtained on transverse test bars taken from the heavy section of the ends, about 13 in. thick, gave the following results:

| | |
|---|---|
| Tensile strength, lb. per sq. in. | 67,750 |
| Yield point, lb. per sq. in. | 37,000 |
| Proportional limit, lb. per sq. in. | 24,500 |
| Elongation in 2 in., per cent | 31.2 |
| Reduction of area, per cent | 41.5 |

## TEST ARRANGEMENTS

To reduce the volume of the water space at test and to simulate conditions of actual service, there was arranged to be inserted in the test pipe a thick-walled cylinder having ends closely fitting

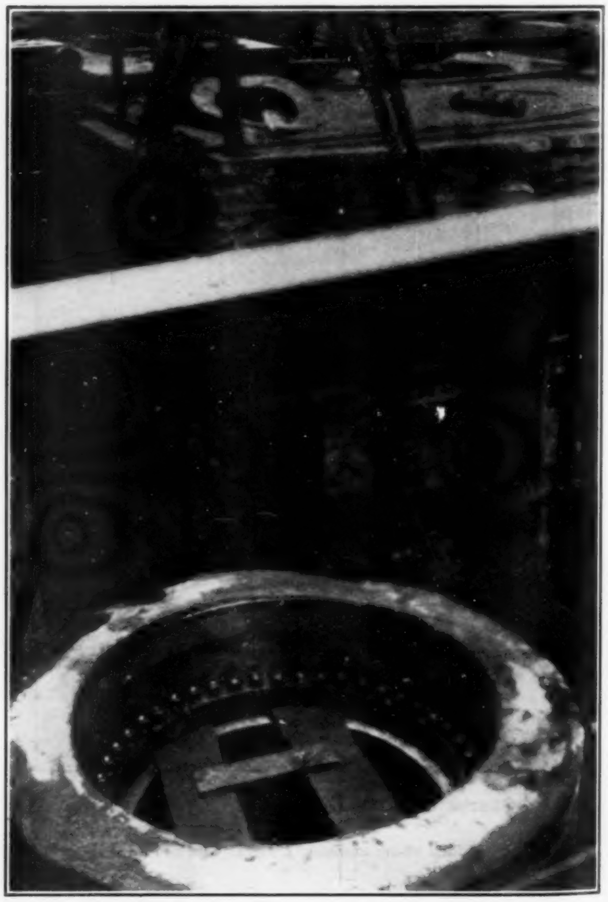

FIG. 4 UPPER END OF PIPE

the bore of the pipe and fitted with U-leathers. A slight reduction in diameter of the inner cylinder between its fitted ends and a slight increase in diameter of the pipe between the same points, provided a small annular space for the high-pressure water.

Fig. 2 shows how the pipe section was fitted with its inner cylinder. This had an average inside diameter of 52 in., an outside diameter of $65^1/_8$ in., and an elastic limit of 38,300 lb. per sq. in.

The heavy flange at each end of the pipe was intended to prevent failure of the U-leathers by an increase in the clearance between inner cylinder and pipe through expansion of the latter under pressure.

Fig. 3 shows the pipe being fitted up, and Fig. 4 the upper end of the pipe with the retaining ring of its U-leather.

Pressure was supplied by a motor-driven test pump with a capacity of two gallons per minute up to 6000 lb. pressure. There were provided the following measuring instruments:

One indicating pressure gage, range 0 to 4000 lb., read for pressures up to 3500 lb. for accurate determination of the elastic limit of the pipe. This was shut off at the higher pressures.

One indicating pressure gage, range 0 to 10,000 lb., read for pressures from 3500 lb. up to final pressure.

One recording pressure gage, range 0 to 15,000 lb., one revolution in two hours, operating during the entire test.

Four Ames indicating dials, range 0 to 0.250 in., measuring radial expansions at four points 90 deg. apart at mid-length of the pipe, read for pressures up to 2600 lb.

Four electric expansion indicators, range 0 to 8 in., reading to $^1/_4$ in., each consisting of a guided bar forced at one end against the outside of the pipe by a spring and carrying on the other end a slide passing over a series of closely spaced contacts, each contact connected to one of a series of indicating lamps mounted on a board with corresponding indicated expansions marked on an adjoining scale. These indicators were applied at the same points as the Ames dials when the latter were removed,

Fig. 5 Electric Expansion Indicator—Contacting End

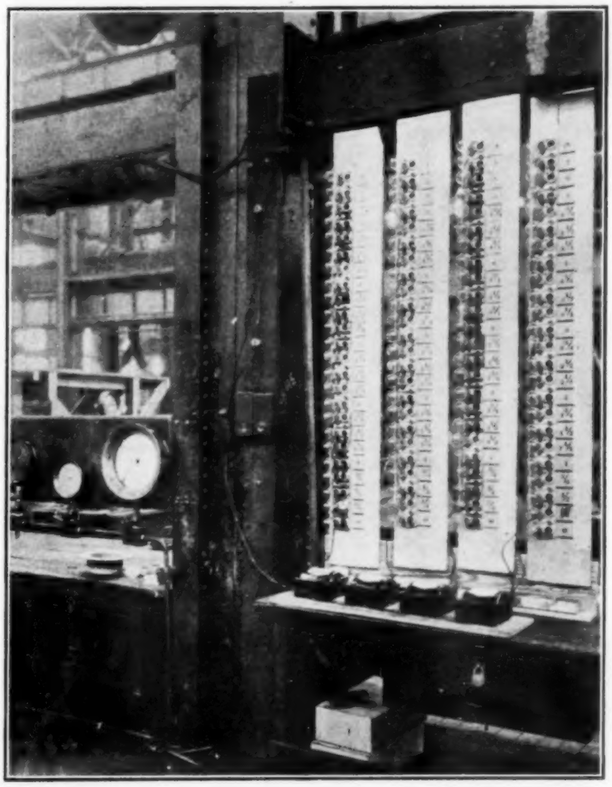

Fig. 6 Electric Expansion Indicator—Indicating End

and measured the radial expansion from 2600 lb. up to the bursting pressure. Fig. 5 shows the contacting end and Fig. 6 the indicating end of these devices.

There were also:

Three mechanical expansion indicators, each formed of a steel wire fastened at one end to a fixed object near the pipe, wrapped one turn around the lubricated body of the pipe and, after running over suitably arranged pulleys, suspending at the other end a counterweight with a pointer indicating on a vertical scale at its side the circumferential expansion of the pipe. These indicators were applied respectively at 6 in. below the top, 6 in. below the middle, and 6 in. above the bottom of the $3^1/_{32}$-in.-thick portion of the wall, and operated during the entire test.

The recording and indicating pressure gages were specially calibrated by the Bureau of Standards for this test, and the observed readings were corrected accordingly.

The general arrangement of the test is shown in Fig. 7. To avoid accidents the pipe with its inner cylinder in position was placed in a concrete pit and the pit covered with armor plates. The pump, pressure gages, and the expansion indicating devices, with the exception of the Ames dials, were mounted on the floor above at a safe distance.

The Ames dials and, later, the contactors of the electric expansion indicators were mounted on a rigid structural-steel frame surrounding the pipe and resting independently on the concrete floor of the pit, upon which the pipe was also firmly supported on end. Fig. 8 shows this frame with the Ames dials in position, and Fig. 9 shows the electrical gages in position after removal of the dials at 2600 lb. pressure.

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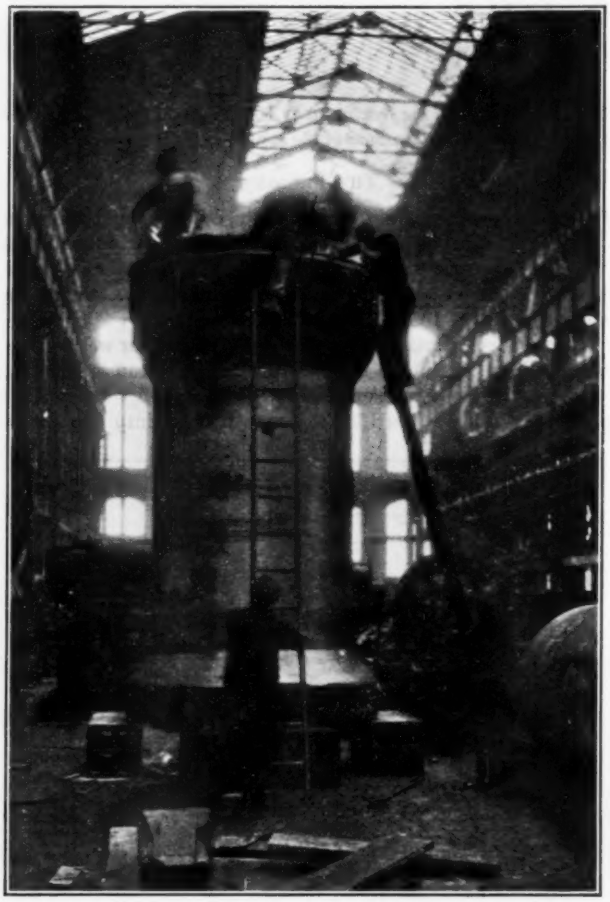

Fig. 3 Fitting Up the Pipe

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| Elongation in 2 in., per cent | 25 |

Each section was to be subjected for 15 min. to an internal hydrostatic pressure of twice its static working pressure. The thickness of sections was based on an allowable stress in the metal of 12,000 lb. per sq. in. under full static head, calculated by Birnie's formula for open-end cylinders with thick walls: namely,

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where $P$ = internal pressure in pounds per square inch
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### Manufacture

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After reheating, the ingot was cropped, punched, expanded, and forged under a 9000-ton hydraulic press, then lightly annealed. The average physical properties obtained on transverse test bars taken from the heavy section of the ends, about 13 in. thick, gave the following results:

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|---|---|
| Tensile strength, lb. per sq. in. | 67,750 |
| Yield point, lb. per sq. in. | 37,000 |
| Proportional limit, lb. per sq. in. | 24,500 |
| Elongation in 2 in., per cent | 31.2 |
| Reduction of area, per cent | 41.5 |

### Test Arrangements

To reduce the volume of the water space at test and to simulate conditions of actual service, there was arranged to be inserted in the test pipe a thick-walled cylinder having ends closely fitting

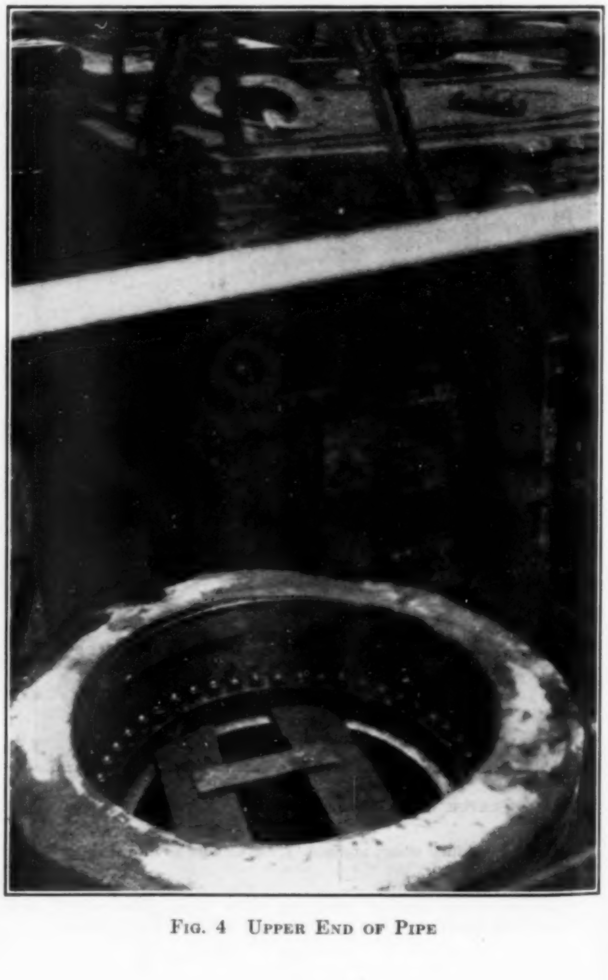

Fig. 4 Upper End of Pipe

the bore of the pipe and fitted with U-leathers. A slight reduction in diameter of the inner cylinder between its fitted ends and a slight increase in diameter of the pipe between the same points, provided a small annular space for the high-pressure water.

Fig. 2 shows how the pipe section was fitted with its inner cylinder. This had an average inside diameter of 52 in., an outside diameter of $65^1/_8$ in., and an elastic limit of 38,300 lb. per sq. in.

The heavy flange at each end of the pipe was intended to prevent failure of the U-leathers by an increase in the clearance between inner cylinder and pipe through expansion of the latter under pressure.

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Pressure was supplied by a motor-driven test pump with a capacity of two gallons per minute up to 6000 lb. pressure.

There were provided the following measuring instruments:

One indicating pressure gage, range 0 to 4000 lb., read for pressures up to 3500 lb. for accurate determination of the elastic limit of the pipe. This was shut off at the higher pressures.

One indicating pressure gage, range 0 to 10,000 lb., read for pressures from 3500 lb. up to final pressure.

One recording pressure gage, range 0 to 15,000 lb., one revolution in two hours, operating during the entire test.

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Four electric expansion indicators, range 0 to 8 in., reading to $^1/_4$ in., each consisting of a guided bar forced at one end against the outside of the pipe by a spring and carrying on the other end a slide passing over a series of closely spaced contacts, each contact connected to one of a series of indicating lamps mounted on a board with corresponding indicated expansions marked on an adjoining scale. These indicators were applied at the same points as the Ames dials when the latter were removed, and measured the radial expansion from 2600 lb. up to the bursting pressure. Fig. 5 shows the contacting end and Fig. 6 the indicating end of these devices.

Fig. 5 Electric Expansion Indicator—Contacting End

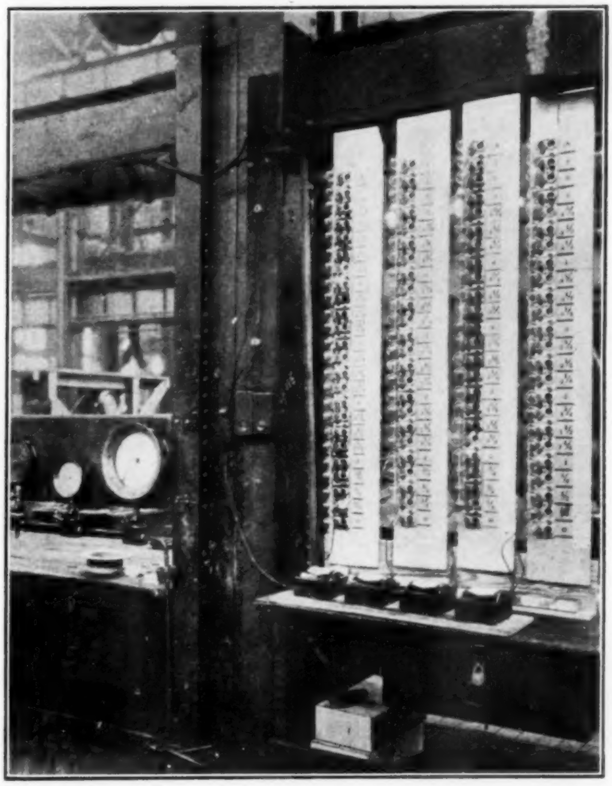

Fig. 6 Electric Expansion Indicator—Indicating End

There were also:

Three mechanical expansion indicators, each formed of a steel wire fastened at one end to a fixed object near the pipe, wrapped one turn around the lubricated body of the pipe and, after running over suitably arranged pulleys, suspending at the other end a counterweight with a pointer indicating on a vertical scale at its side the circumferential expansion of the pipe. These indicators were applied respectively at 6 in. below the top, 6 in. below the middle, and 6 in. above the bottom of the $3^1/_{32}$-in.-thick portion of the wall, and operated during the entire test.

The recording and indicating pressure gages were specially calibrated by the Bureau of Standards for this test, and the observed readings were corrected accordingly.

The general arrangement of the test is shown in Fig. 7. To avoid accidents the pipe with its inner cylinder in position was placed in a concrete pit and the pit covered with armor plates. The pump, pressure gages, and the expansion indicating devices, with the exception of the Ames dials, were mounted on the floor above at a safe distance.

The Ames dials and, later, the contactors of the electric expansion indicators were mounted on a rigid structural-steel frame surrounding the pipe and resting independently on the concrete floor of the pit, upon which the pipe was also firmly supported on end. Fig. 8 shows this frame with the Ames dials in position, and Fig. 9 shows the electrical gages in position after removal of the dials at 2600 lb. pressure.

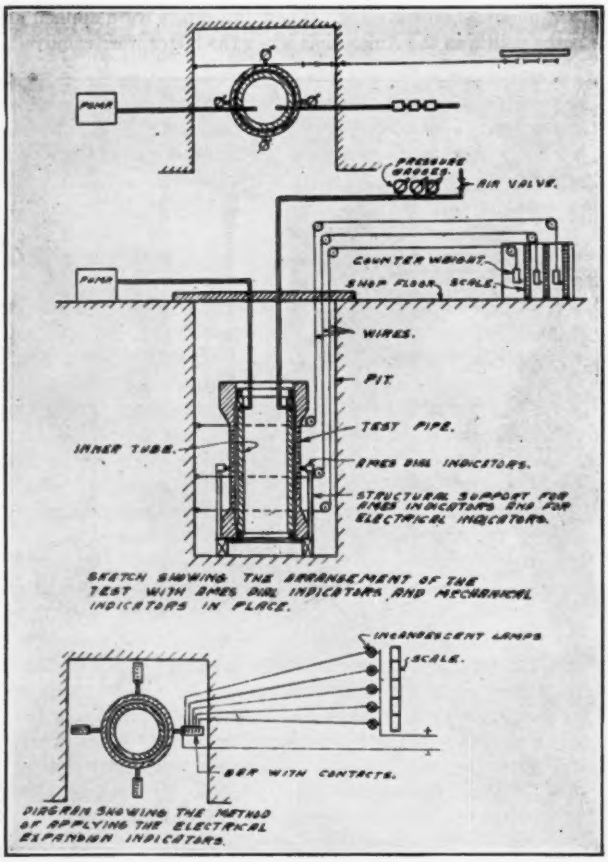


FIG. 7 SKETCH SHOWING (*a*) ARRANGEMENT OF TEST WITH AMES DIAL INDICATORS AND MECHANICAL INDICATORS IN PLACE, AND (*b*) METHOD OF APPLYING THE ELECTRICAL EXPANSION INDICATORS

## THE TEST

A preliminary test under a pressure of 1800 lb. developing no leaks of the U-leathers or at the joints of the piping, the official test began at 10:20 a.m. the following day in the presence of engineers of Messrs. Stone & Webster, representing the purchaser, and representatives of The Midvale Company and of the Bethlehem Steel Company.

The system forefilled and the air valve closed, pressure was gradually raised to 2600 lb., readings of the radial expansions being taken with the Ames dial indicators at pressures of 500, 750, 1000, 1250, 1500, 1600, 1700, 1800, 1900, 2000, 2100, 2200, 2300, 2350, 2400, 2500, and 2600 lb. per sq. in. As the readings were taken, two curves were plotted, each representing the average radial expansion of two diametrically opposite points on the pipe as a function of the pressure.

At 2600 lb. pressure it was evident from both curves that the elastic limit had been certainly passed, the pump was stopped, the dial indicators removed, and the electrical indicators put in their place. The pressure was again increased. At 11:25 a.m. at 3400 lb. pressure, a pipe joint leaked, requiring a relief of pressure to make repairs.

At 12:04 p.m., the pump was again started and expansions recorded up to a pressure of 4200 lb., when, at 12:35 p.m., a leaking joint compelled a second interruption. Repairs were completed at 1:50 p.m., the pump started and expansion readings taken up to 3:03 p.m., when at a pressure of 5300 lb. per sq. in. and with a loud report, the pipe burst.

Figs. 10, 11, and 12 show the manner in which the fracture occurred, as predicted by Dr. F. C. Langenburg, consulting metallurgist of the Watertown Arsenal, from the results of his experiments on gun forgings.

The crack extended entirely through the bottom flange, with a crack at right angles to it at the point of stress concentration between the body and the bevel of the flange. The two arms of the V-shaped crack at the upper end partly encircled the forging there in the same region of maximum stress and then bent downward, as will be seen in Fig. 4, nearly meeting at the opposite side of the forging.

## RESULTS

On Fig. 13 are shown curves plotted from the readings of the various devices for measuring expansion. They represent the diametral expansion of the pipe as a function of the pressure, throughout the entire period of the test.

From 0 to 2600 lb. pressure the left curve shows the average of the readings from the four Ames dial indicators. At that pressure they were removed, the electric expansion indicators were emplaced, and thereafter the latter gave four closely parallel curves which were averaged and are shown as one curve.

The readings of the two mechanical indicators near the ends of the pipe were closely alike and, similarly averaged, are shown as one curve.

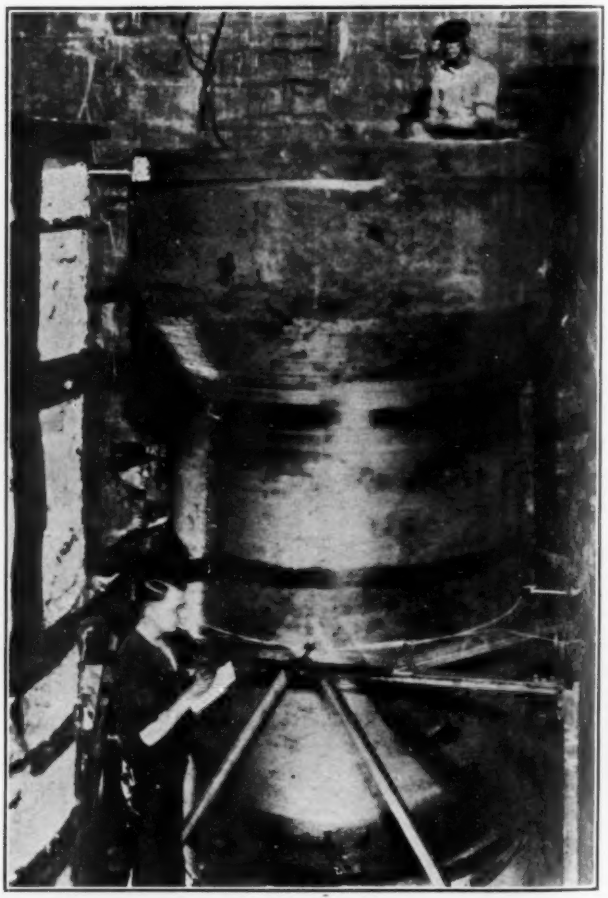

FIG. 8 READING THE AMES DIALS

The straight dotted line shows anticipated diametral expansions up to 2500 lb. internal pressure, based on stresses derived by Birnie's formula and a modulus of elasticity of 30,000,000 for the steel.

The expansion curves show clearly that the proportional limit of the steel was reached at 2150 lb. pressure, producing, as shown in Fig. 14, a tangential stress in the pipe wall of 25,000 lb. per sq. in. This agrees closely with the 24,500 lb. proportional limit of the transverse-test bar.

The soundness of the formula is further shown by the substantial agreement of the actual and anticipated expansions.

Fig. 14 shows the tangential stresses in the walls of the cylinder as a function of the pressure, using the Birnie formula and disregarding the limitation of the formula to stresses within the proportional limit.

According to this curve, the wall stress produced by the bursting pressure of 5300 lb. would be 62,000 lb. per sq. in. This is somewhat less than the tensile strength of the transverse-test bar, 67,750 lb. The difference shows the error of the formula when extended beyond its recognized limitations, while emphasizing by its small amount the unexpectedly close approximation of the formula to the truth.

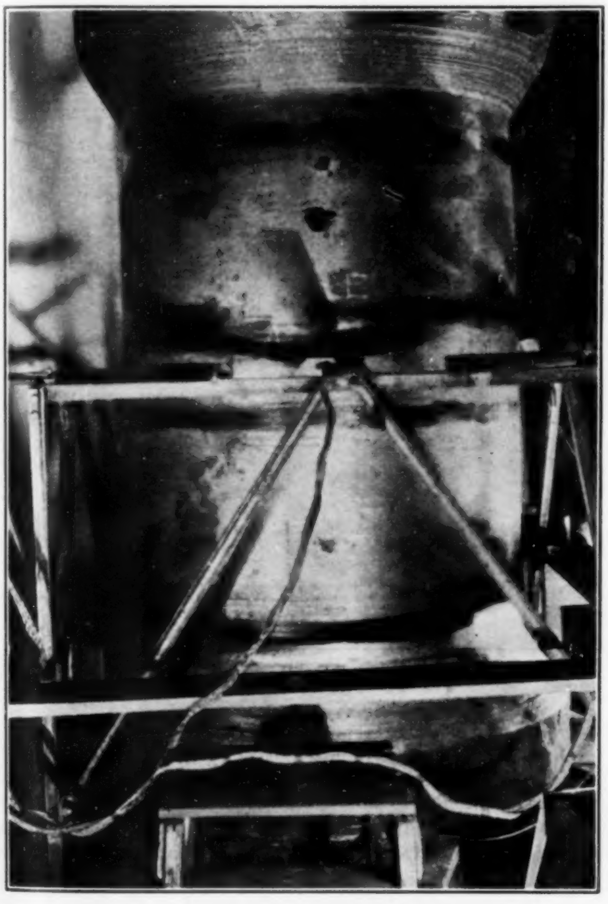

FIG. 9 ELECTRICAL INDICATOR IN PLACE

As previously stated, transverse-test bars cut from the metal of the flanges of the pipe for test averaged:

| | |
|---|---|
| Tensile strength, lb. per sq. in. | 67,750 |
| Yield point, lb. per sq. in. | 37,000 |
| Proportional limit, lb. per sq. in. | 24,500 |
| Elongation in 2 in., per cent | 31.2 |
| Reduction of area, per cent | 41.5 |

After the test transverse-test bars were taken at the root of the lower flange where the expansion was 2 per cent due to the restraining influence of the flange, the results averaging:

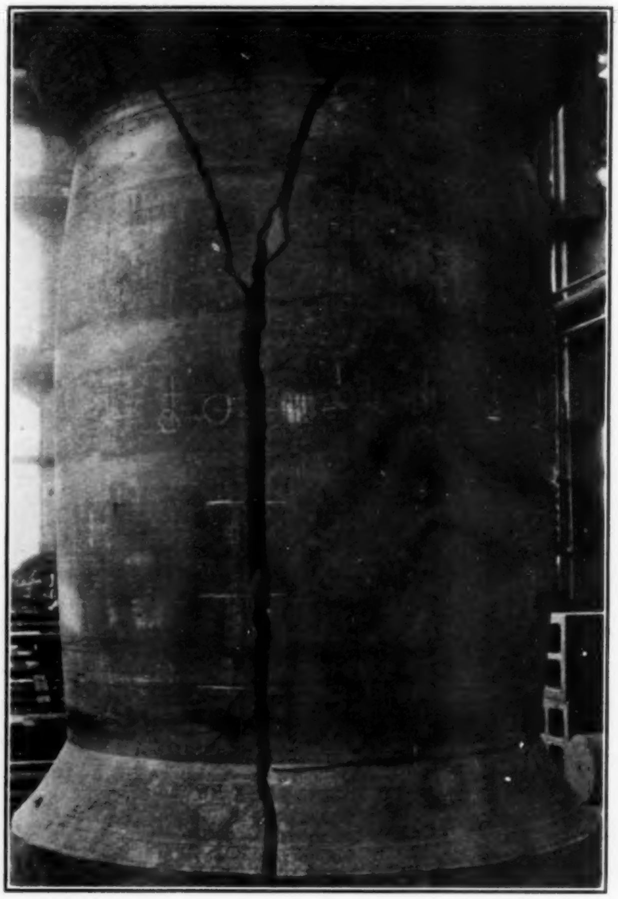

FIG. 10 FRACTURE, FRONT VIEW

| | |
|---|---|
| Tensile strength, lb. per sq. in. | 64,000 |
| Yield point, lb. per sq. in. | 43,500 |
| Proportional limit, lb. per sq. in. | 33,500 |
| Elongation in 2 in., per cent | 26.1 |
| Reduction of area, per cent | 53.7 |

A transverse-test bar was also taken at the mid-length of the forging where the expansion averaged 8.96 per cent which gave:

| | |
|---|---|
| Tensile strength, lb. per sq. in. | 75,000 |
| Yield point, lb. per sq. in. | 68,000 |
| Proportional limit, lb. per sq. in. | 50,000 |
| Elongation in 2 in., per cent | 17.0 |
| Reduction of area, per cent | 37.2 |

These figures show the extent to which the metal was work-hardened by the cold-working to which it had been subjected.

An examination of the readings of the electrical and mechanical indicators taken beyond the proportional limit of the steel shows a fairly close agreement, considering their relative positions—at the center and 6 in. below it—and the difference in their methods of operation. They give a diametral expansion at the mid-length of the pipe of somewhat over 6 in. at the moment of failure. The circumferential measurements taken after fracture give a diametral expansion of $6^1/_4$ in. as shown in Fig. 15. In the calculations that follow, 6 in. is taken as being certain.

The form and extent of the fracture and the final shape of the pipe are also shown in this sketch. The main crack occurred in the quadrant where the wall was originally thinnest.

The original wall thickness of the middle of the pipe in the quadrant of rupture was 3 in., reduced to $2^{13}/_{16}$ in. after test,

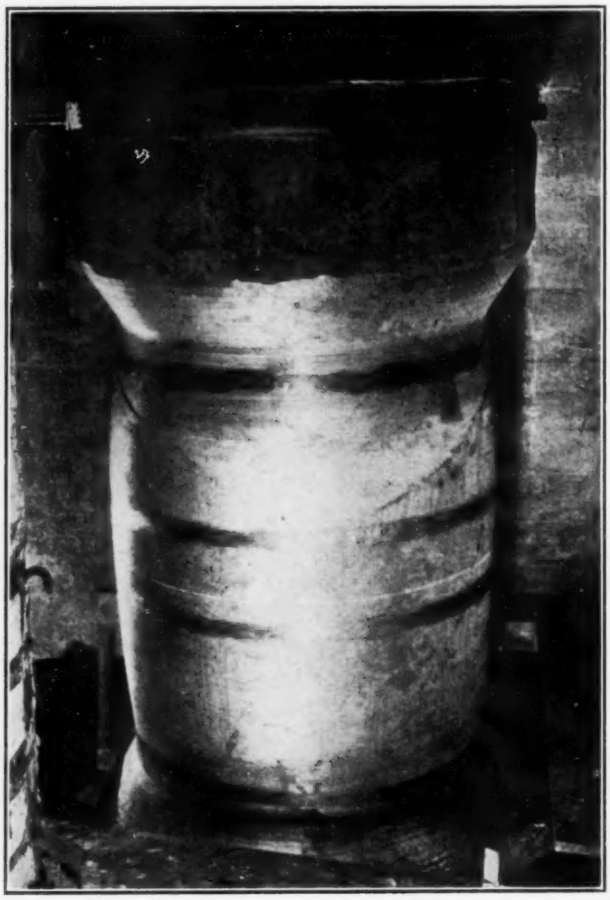

FIG. 11 FRACTURE, REAR VIEW

FIG. 12 FRACTURE, SIDE VIEW

giving a reduction in wall thickness of $^3/_{16}$ in. or 6.25 per cent.

The initial outside diameter of the pipe was $72^1/_4$ in., the final diameter $72^1/_4$ in. + 6 in. = $78^1/_4$ in.; corresponding to an expansion of 8.3 per cent.

The initial inside diameter of the pipe was $66^3/_{16}$ in., and after test $66^3/_{16}$ in. + 6 in. expansion + $^3/_8$-in. reduction in two wall thicknesses = $72^9/_{16}$ in., giving an inner diametral expansion of 9.63 per cent. The mean expansion was therefore $(8.3 + 9.63) \div 2 = 8.96$ per cent.

The burst pipe was cylindrical for a distance of from 4 in. to $7^1/_2$ in. at the mid-length, indicating that the section there was not influenced by the proximity of the reinforced ends, and that the effect produced there would have continued for any additional length the pipe might have had.

### Summary of Results

The pipe reached its elastic limit at a pressure of 2150 lb. corresponding to a tangential stress of 25,000 lb. per sq. in. in the steel of the walls, the measured proportional limit of the steel at the ends being 24,500 lb.

The pipe failed at a pressure of 5300 lb. which, by the approximation of the extended Birnie formula, would correspond to a fiber stress of 62,000 lb. per sq. in., compared with an actual tensile strength of 67,750 lb.

The external expansion in diameter was 6 in., or 8.3 per cent. The internal expansion was $6^3/_8$ in. or 9.63 per cent. The mean expansion of the wall was 8.96 per cent. The reduction in wall thickness at the mid-length of the pipe at the fracture was $^3/_{16}$ in. or 6.25 per cent.

### Observations

It is seldom that an opportunity is afforded engineers for comparing the elastic and breaking strengths of a large forging with that of its representative test bars—and it is encouraging to note that they appear to be in such good accord. A foundation is laid for confidence that test bars properly located will truly indicate the average behavior of the metal in the large forging from which they may be taken.

It appears that an internal pressure producing a calculated stress practically equal to the proportional limit of its metal can be withstood without permanent deformation by a seamless forged-steel pipe; and that it may fail at about the pressure given by the Birnie formula arbitrarily extended to the ultimate strength.

Ductility has always been considered of great advantage in the walls of any vessel as enabling them to yield to sudden overpowering stress and so reduce the severity of the shock. There is also great gain in the substitution of swelling or splitting of the walls,

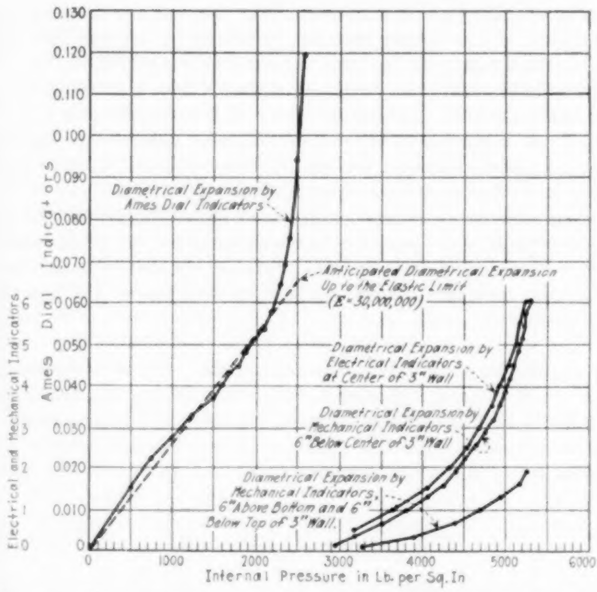


FIG. 13 CURVES PLOTTED FROM READINGS OF THE VARIOUS DEVICES FOR MEASURING EXPANSION, AND SHOWING DIAMETRAL EXPANSION OF PIPE AS A FUNCTION OF PRESSURE

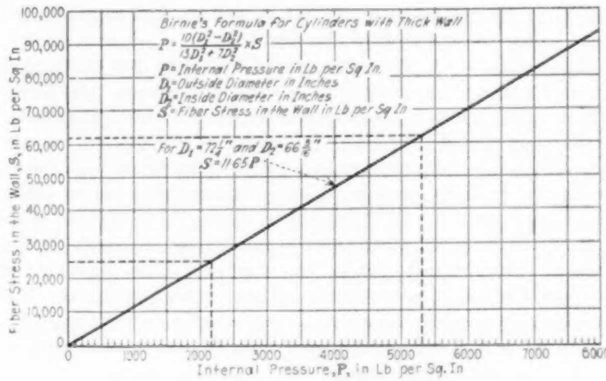


FIG. 14 TANGENTIAL STRESSES IN WALLS OF CYLINDER AS A FUNCTION OF THE PRESSURE, USING BIRNIE FORMULA AND DISREGARDING ITS LIMITATION TO STRESSES WITHIN THE PROPORTIONAL LIMIT

with gradual relief of pressure, for the explosive relief of shattering.

A further advantage lies in the visual evidence of distress given by a positive swelling, enabling replacement of a part before its destruction occurs.

The experiment just reported indicates another advantage not usually recognized.

Within recent years much progress has been made in the construction of light ordnance by the process of autofrettage—the preliminary expansion by hydraulic pressure of an underbored gun. By a stretching beyond its elastic limit the metal of the bore is, on relief of pressure, left in a state of initial compression while the outer layers are in moderate initial tension, the effect being similar to that of a built-up gun. The usual amount of initial expansion is about 5 per cent of the diameter.

The same effect has been produced in the walls of this representative pipe. The stress produced in the original wall by 1050 lb., the highest pressure in the system, would be about 12,500 lb., giving a factor of safety of 2 compared with the original proportional limit in the steel of 24,500.

The expanded pipe, having a proportional limit of 50,000, would carry with the same factor of safety an internal pressure of 1840 lb. Therefore, just before bursting the expanded pipe was as safe, theoretically, for 1840 lb. pressure as a brittle pipe for 1050 lb. pressure.

The pronounced expansion shown by the seamless forged-steel pipe tested indicates both that it is an eminently safe type of pipe, able to bear excessive loads without fracture, and that it may be relied upon to give ample warning of danger in case of weakening through corrosion or otherwise.

## Discussion

E. O. WATERS.[2] The test reported by the author is extremely interesting as a check on existing theories of the strength of cylinders. The fact that the ultimate strength as computed by Birnie's formula falls considerably below that obtained from the test bars is of far less significance than the close agreement between the actual and theoretical stretch within the elastic limit. The curves in Fig. 13 (below the elastic limit) prove unmistakably the soundness of a formula that is based on maximum strains and takes account of the interrelation of the principal stresses, in accordance with St. Venant's hypothesis.

The writer has had recent occasion to investigate the stresses in pipe flanges, and wishes to state emphatically that the St. Venant principle, when applied to a theoretical analysis of flanges, gave a most satisfying agreement with the deflections obtained by test. In the present instance, the expansion calculated from the thin-cylinder formula would be appreciably less than that given by the dotted line in Fig. 13, i.e., 0.050 in. or less at 2000 lb. per sq. in. internal pressure, depending upon what diameter is used; and the ultimate strength

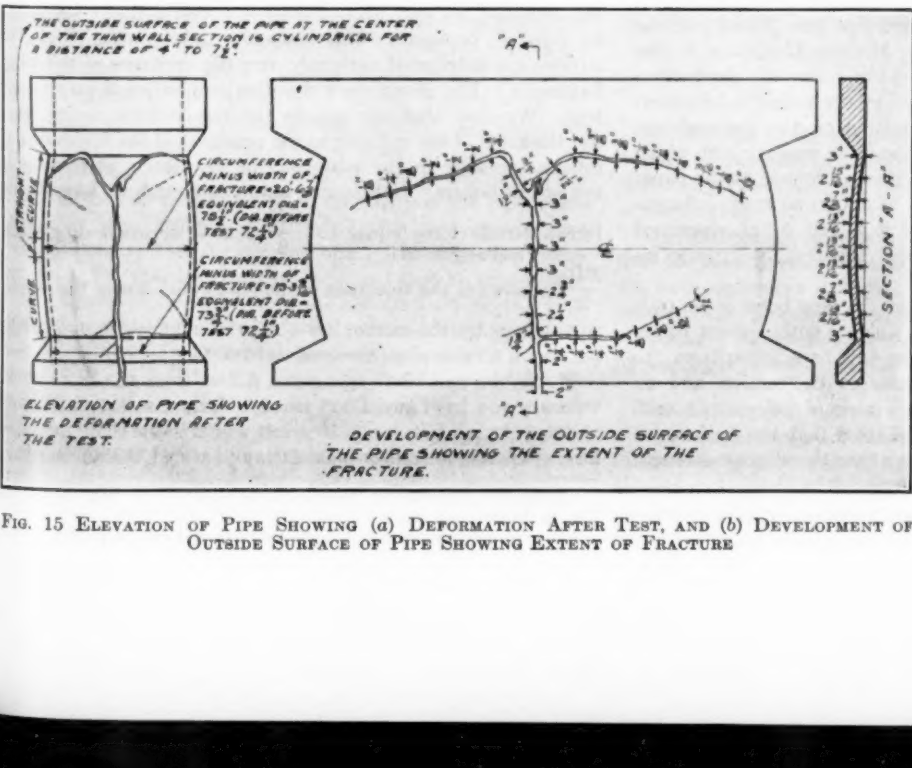


FIG. 15 ELEVATION OF PIPE SHOWING (a) DEFORMATION AFTER TEST, AND (b) DEVELOPMENT OF OUTSIDE SURFACE OF PIPE SHOWING EXTENT OF FRACTURE

[2] Assistant Professor of Mechanical Engineering, Yale University, New Haven, Conn. Mem. A.S.M.E.

would figure out as about 57,900 lb. per sq. in., some 16 per cent below the strength of the test bars.

The author's computed strength of 62,000 lb. per sq. in. was evidently figured on the original diameter of the pipe. But allowing for the increase in total hydrostatic load due to the expanded inside diameter of the pipe at the instant of failure, it is easy to show that the ultimate strength is 67,600 lb. per sq. in.; this is computed without assuming any shrinkage in wall thickness, which obviously would be in error, as it would be akin to computing the ultimate strength of a tensile-test specimen on the basis of the reduced area of the fracture. This figure, while unimportant, may be considered as corroboration of the other results and a further proof of the soundness of the formulas.

Checking the test results according to the maximum-shear theory, we have the following:

Average shearing strength of test bars, 67,750 ÷ 2 = 33,875 lb. per sq. in.

Maximum radial stress in pipe, 5300 lb. per sq. in., compression.

Maximum hoop stress, based on expanded pipe, with no reduction in wall thickness, 66,029 lb. per sq. in., tension.

Corresponding shear stress, (66,029 + 5300) ÷ 2 = 35,663 lb. per sq. in. This is not as good an agreement as the one just given on the basis of the maximum-strain theory using the expanded inside diameter, but is a better correlation than that given by the maximum-strain theory based on the original diameter.

H. L. Doolittle.[3] In the design of the penstock for the new Big Creek Power Plant No. 2 of the Southern California Edison Company, several interesting and difficult problems were encountered. This plant will contain two 56,000-hp. units operating under a head of approximately 2400 ft. Economic studies showed that it would be desirable to depart from the usual practice of installing one penstock for each unit and use instead a single pipe line to a point adjacent to the power house where laterals would be installed to branch to the two units.

The use of a single line to supply these two large units under this high head required a diameter of 66 in. at the bottom with a wall thickness of 3 in. After making an investigation of the different ways in which this pipe could be built, it was finally decided to use seamless steel forgings with integrally forged flanges. As this company had never used any material of this description, it was stated in the contract that a piece of pipe, representing the heaviest section, should be tested to destruction before proceeding with the manufacture of the penstock proper.

While equal contracts for this forged pipe were placed with the Bethlehem Steel Company and the Midvale Company, it was decided to have the Midvale Company make the destruction test. This test is very ably described by the author in his paper, and his company is to be congratulated on the thoroughness with which they carried out the test and the rapidity with which all of the work in connection therewith was done. As the paper shows, every precaution was taken to obtain as much information as possible from the test, and it is felt by all concerned that the information obtained amply justified the expense involved.

It was very gratifying to note that the pipe burst at an ultimate stress of 62,000 lb. per sq. in., which is within about 10 per cent of the ultimate strength of the test bars taken from the forging. Observations on other tests to destruction and on penstocks that have failed in service, made of different material and by different processes, have indicated that the failures occurred at stresses very materially lower than the ultimate strength of the test bars.

[3] Chief Designing Engineer, Southern California Edison Co., Los Angeles, Calif. Mem. A.S.M.E.

Another very gratifying result of the test was the proof of the ductility of this forged material, indicated by a 9 per cent increase in diameter at the time of failure. In addition to this increase in diameter, the thickness reduced a little over 6 per cent. It is felt that this ductility is a very desirable quality in a penstock, as operating conditions are likely to subject the pipe to severe water hammer. The more brittle the metal, the less able it is to withstand these sudden shocks.

The observations made in the paper regarding the increase in the strength of the pipe due to its expanding under pressure are of interest, but it is doubtful if operating companies would take this into consideration and reduce the thickness of the pipe on that account.

A. M. Wahl.[4] The author has applied the Birnie formula for stress in thick cylinders to this case. It is also instructive to apply Lamé's formula[5] for thick cylinders to this pipe and see how it checks with the Birnie formula. Lamé's formula is, using the notation of the paper,

$$S = \frac{PD_2^2}{D_1^2 - D_2^2}\left(1 + \frac{D_1^2}{4R^2}\right) \qquad [1]$$

where $R$ is the distance from the axis of the thick cylinder at which the stress $S$ exists. It is clear from this formula that the stress is a maximum at the inner edge, i.e., when $R = D_2$. This maximum value is

$$S_{\text{max.}} = \frac{PD_2^2}{D_1^2 - D_2^2}\left(1 + \frac{D_1^2}{D_2^2}\right) \qquad [2]$$

Substituting in Equation [1] the dimensions given by the author we obtain, at an internal pressure of 2150 lb. per sq. in. corresponding to the elastic limit found by test, a stress distribution over the cross-section of the pipe as shown in Fig. 16. The maximum stress occurs along the inside edge and is equal to 24,650 lb. per sq. in. while the minimum stress occurs at the outside edge and is equal to 22,500 lb. per sq. in. The value of of the maximum stress obtained in this way, i.e., 24,650 lb. per sq. in., is quite close to the value of proportional limit found by the author using test pieces cut from the flange of the pipe. It also does not differ greatly from the value of 25,000 lb. per sq. in. obtained by the author using the Birnie formula. These figures indicate that both the Lamé and Birnie formulas give results quite close to the actual test results.

Since the pipe-wall thickness is quite small compared with the diameter, we may also consider it a thin cylinder subjected to internal pressure. This amounts to assuming that the stresses are distributed uniformly over the thickness of the pipe. Reference to Fig. 16 will show that this supposition is very nearly true. We may therefore equate the tensile force acting over the thickness of the cylinder to the resultant of the forces due to internal pressure in the same way as we determine stresses in cylindrical boilers. Considering unit axial length we have therefore a tensile force equal to $\frac{PD_2}{2}$ and a corresponding stress $\frac{PD_2}{2t}$, where $t$ is the thickness of the pipe wall. Using the dimensions given by the author we obtain at a pressure of 2150 lb. per sq. in. a value of stress equal to 23,500 lb. per sq. in.

It may be seen that this stress differs from the more exact values given by Lamé's and Birnie's formulas above, by only about 6 per cent or less. Hence it would seem that, for pipes having the relative dimensions of the pipe tested, it is unnecessary

[4] Research Laboratory, Westinghouse Electric & Manufacturing Co., E. Pittsburgh, Pa.

[5] See "Applied Elasticity," Timoshenko and Lessells, p. 252.

to apply thick-cylinder formulas to obtain reasonably accurate results.

It is hard for the writer to accept without qualification the statement made at the end of the paper that "the metal of the bore is, on relief of pressure, left in a state of initial compression, while the outer layers are in a state of moderate initial tension." This effect undoubtedly occurs to a considerable degree in guns when subjected initially to high pressure, but in such cases the wall thickness of the gun is quite large compared to the diameter. Hence the stress distribution below the elastic limit is somewhat as shown by the shaded area of Fig. 17, a peak of stress occurring along the bore. When stressed by internal pressure the material at the bore most quickly reaches its elastic limit. After this occurs, permanent set is produced and the peak of stress is cut off. On relieving the pressure, high residual stresses of opposite sign are induced at the bore.

On the other hand, when the stress distribution is very nearly uniform, which, as indicated by Fig. 16, was the case for this penstock pipe, there is no sharp peak of stress to be cut off as is the case with guns. Consequently no very high residual stresses can be induced. Such a case would be similar to attempting to induce high residual stresses in a tension test piece by stressing beyond the elastic limit in a tension-testing machine and then relieving the load.

There is no doubt that, as the author states, the proportional limit of the material is raised by overstraining the metal. But it must also be noted that the author's tests show that the ultimate strength of the test bars cut out after failure of the pipe did not show a corresponding increase. Hence, in view of this fact and what has been mentioned above, the writer cannot agree entirely with the statement that "just before bursting the expanded pipe was as safe theoretically for 1840 lb. pressure as a brittle one for 1050 lb. pressure."

The writer takes this statement to mean that the factors of safety against bursting for a brittle pipe at 1050 lb. pressure and for a ductile pipe at 1840 lb. would be equal. Since, as shown above, only a small amount of residual stress is induced by overstraining, and since the ultimate strength is not greatly raised by such treatment, it is possible, in the writer's opinion, that the factors of safety against bursting for the ductile pipe and the brittle pipe would not be greatly different provided the ultimate strength of both kinds of material is the same, and assuming that no stress concentration, due to holes, fillets, or other causes exists, and that no initial ellipticity of the pipe cross-section due to fabrication is present.

Since in practical pipes there is always some concentration of stress near holes, flanges, outlets, etc., the ductile pipe is superior because it will allow yielding of the material without failure at points of concentration of stress; consequently the stresses are reduced by virtue of this yielding. On the other hand, brittle materials would allow a crack to open.

A further reason for the superiority of the ductile pipe arises because of the fact that some initial ellipticity of the pipe cross-section may arise during fabrication, i.e., the cross-section may deviate somewhat from the circular form. The writer has calculated, using the analysis given in his paper,[6] that an initial ellipticity or maximum deviation from the circular form of the pipe cross-section equal to one-sixth the thickness of the pipe wall, will approximately double the maximum stress set up by internal pressure. These calculations have recently been verified by strain measurements made by the writer on large pipe bends for steam turbines. For example, it was found that in a 10-in. expansion bend for a steam turbine at points where the ellipticity was about 0.1 in., the stress in the circumferential direction due to an internal pressure alone of 1000 lb. per sq. in., varied from about 1000 lb. per sq. in. compression to about 24,000 lb. per sq. in. tension. Herein lies an important advantage of the ductile pipe. The ductile pipe will on overstressing allow yielding so that the pipe cross-section will more nearly approximate the circular form with consequent decrease in ellipticity of the cross-section, thereby producing a more uniform stress distribution. On the other hand, the brittle pipe will not allow this yielding but may allow a crack to open, with consequent failure at a much lower internal pressure than would be the case for a similar pipe of ductile material.

The writer would also like to point out the fact that the "true ultimate strength" as found by the pipe test was quite different from the "true ultimate strength" of the test pieces cut out from the pipe. By "true ultimate strength" is meant the actual stress existing in the metal at the instant of failure, i.e., the stress calculated on the actual sectional area existing at the time of fracture. Using the data on ultimate strength and reduction of area given by the author, the writer has calculated the "true ultimate strength" for the test bars cut out from the pipe. These values are given below.

| Bar location | Average true ultimate strength lb. per sq. in. |
|---|---|
| Bars cut from flanges before test........ | 115,800 |
| Bars cut from root of flanges after test... | 138,000 |
| Bars cut from mid-length of forging..... | 119,400 |

In order to get the true ultimate strength possessed by the metal of the pipe we may proceed as above, considering the pipe

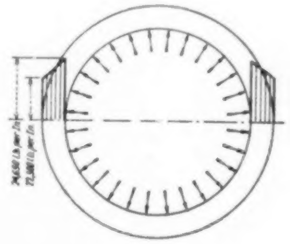

Fig. 16

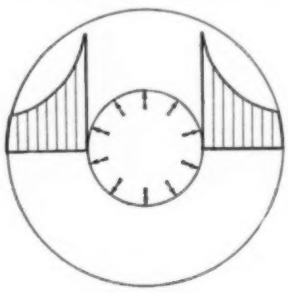

Fig. 17

a thin cylinder and taking the actual inside diameter $D'$ existing at the moment of failure. We also take the reduced thickness $t'$ found at failure. The calculated value of true ultimate strength is, then, at 5300 lb. per sq. in. pressure,

$$S = \frac{PD'}{2t'} = \frac{5300(72.56)}{2(2.812)} = 68{,}400 \text{ lb. per sq. in.}$$

By reference to the above table it may be seen that this value is only 57 per cent of the value of the true ultimate strength obtained on test bars cut from the material at the mid-length of the forging.

The discrepancy may possibly be accounted for by the fact that the loading conditions in the pipe and in the test bars cut out were somewhat different, i.e., in the test bars free lateral contraction or necking of the material was allowed, while in the pipe lateral contraction in the axial direction was prevented by the rigid fastening of the ends.

The Author. As stated by Professor Waters, in computing the ultimate strength of the pipe the author used the original dimensions to facilitate comparison between allowed and bursting stresses on the pipe as designed, just as the tensile strength of a test bar is referred to the original diameter On this basis there was an effective ratio of 62,000 ÷ 67,750 = 0.91 of the original

[6] See Appendix No. 5 of the writer's paper, "Stresses and Reactions in Expansion Pipe Bends," presented before the annual meeting of the A.S.M.E., 1927.

test-bar strength. If the stresses be calculated on the expanded dimensions it would seem that comparison should be made with the expanded physical properties. On this basis the ratio would be $67{,}600 \div 75{,}000 = 0.90$, a singularly close agreement.

Mr. Wahl has correctly illustrated the elastic stress distribution on thick and thin cylinders; but it is to be remembered that although the breech section of a gun resembles Fig. 17, the muzzle section much more nearly resembles Fig. 16. The effect of overstrain, although far less at the muzzle, is there, and to a certain moderate extent is present in the expanded pipe also. Thus a test bar taken at the inner surface of the cylinder wall at the point of fracture gave 4000 lb. greater proportional limit than was given by a corresponding bar taken at the outer surface, showing the effect of stretching the interior more than the exterior, with a consequent initial compression on relief of the pressure.

The Birnie formula was used by the author in his discussion because it applies to open-end cylinders, whereas the Lamé formula, applying to closed cylinders, gives results too low. The use of U-leathers for packing practically removed all longitudinal stress, making the Lamé formula properly inapplicable, although the divergence is not great. The two formulas differ by from about 4 per cent to 20 per cent, according to the proportion of wall thickness to interior diameter.

In view of the polite criticism given his statement that just before bursting the expanded pipe was as safe theoretically for 1840 lb. pressure as a brittle pipe for 1050 lb., the author feels that an explanation is due.

The effect of cold working on steel is to raise the proportional limit much more rapidly than the tensile strength; thus the original steel of the pipe showed 67,750 lb. tensile strength and 24,500 lb. proportional limit, whereas the cold-worked steel showed 75,000 lb. tensile strength and 50,000 lb. proportional limit—an increase in tensile strength of less than 11 per cent compared with an increase in proportional limit of 104 per cent.

Now it has been the experience of certain water-power companies that brittle pipe bursts at about, or but slightly above, its proportional limit, not developing nearly its ultimate strength—which was therefore not considered. As cold work also embrittles a ductile steel, both metals were compared on a basis of proportional limit only.

It was in view of this comparison that the statement was made. It was not put forward as a suggestion that a lower factor of safety be used in designing pipe lines, but rather to point out the actual existence in seamless forged pipe of a larger factor of safety than had been used in the calculations.

The author does not feel that it would be profitable to go into the question of the so-called "true ultimate strength" because this figure is highly variable, depending, as it does, largely upon the amount of the contraction of area.

# Physical Properties of Alloy Steels Under Various Heat Treatments and at Elevated Temperatures

By C. B. Callomon,[1] Brackenridge, Pa.

*The author confines his treatment to two of the newer and less well-known ferrous alloys: (1) so-called "stainless" iron, a steel containing from 12 to 16 per cent of chromium and less than 0.12 per cent carbon; and a "super" stainless iron containing from 12 to 20 per cent of chromium and 7 to 10 per cent of nickel. The former not only resists corrosion but is readily machinable; it is susceptible to heat treatment, under which it attains remarkable physical properties fitting it for a wide range of engineering applications. The second alloy, the strength of which is increased by hot or cold working rather than by heat treatment, resists corrosion much better than the first one, but is more difficult to form and machine. Further, it is from 7 to 15 per cent lighter than other corrosion-resisting metals and alloys. Both alloys have high tensile strength at elevated temperatures; the latter being the better in this respect, however, having an ultimate tensile strength of 25,500 lb. at 1650 deg. fahr.*

Alloys, both corrosion-resisting and heat-resisting, have been the subject of a considerable number of papers and the theme for a great deal of discussion. The attempt, therefore, to present here any new information pertaining to them may appear presumptuous. It has been the author's privilege, however, to be intimately connected with development work in connection with some of the newer and therefore less well-known ferrous alloys, and it is to these particular alloys that he wishes to confine this paper.

Two specific materials which the author has in mind are produced by the company with which he is associated under the specific trade names of Ascoloy 33 and Allegheny Metal, and are familiar not only under those two names but under many others, since each producer has coined his own designation for the material of his particular manufacture.

Most of us have followed, at least to an extent, the development and exploitation of the alloy which has come to be spoken of as "stainless steel." Its field of usefulness for the manufacture of cutlery is a well-established one. There is, however, a newer and not so well-known member of the stainless-steel family, which, to differentiate it from stainless steel, has come to be called "stainless iron."

## Stainless Iron—What It Is

Stainless iron is a low-carbon stainless steel developed as the result of efforts to produce a stainless steel which would be more workable than the cutlery grade and which would have equal corrosion resistance. As the result of these efforts, there was produced some five years ago an alloy of chromium and iron which when manufactured with low carbon content had just those qualities. As produced under the trade name Ascoloy 33 it contains from 12 to 16 per cent chromium and less than 0.12 carbon, and so-called "stainless iron" is of identical composition. It might be remarked here that the word "stainless" as applied to these chromium-iron alloys is a misnomer; they are not stainless except as compared with some other material.

[1] Manager, Alloy Steel Department, Allegheny Steel Company.

Presented at a meeting of the Philadelphia Section of the A.S.M.E. Philadelphia, Pa., January 24, 1928.

Ascoloy 33, in common with all other stainless irons, will show, under certain conditions, evidence of surface corrosion. The fact that the corrosion occurring under these conditions is a surface one and not a progressive corrosion, is the reason the alloy has such a wide field of utility as a corrosion resistant. Being of the low-carbon grade of chromium-iron alloys, it resists this corrosion in the annealed condition as well as in the heat-treated condition, and in the unpolished state as well as when polished. It is absolutely essential, however, that the surface be free from scale, otherwise corrosion will occur at the boundaries of the scale pits. Stainless steel must be both hardened and polished to become stainless, so that it can be said that the difference between stainless steel and stainless iron is a difference based entirely on carbon content. The low carbon obviates the necessity for hardening and polishing. Why this is so is readily explainable, but need not be gone into here.

Ascoloy 33 is ductile and malleable. It is readily machinable and can be formed and drawn. It may be welded, soldered, and brazed. It is procurable in all commercial forms except structural shapes.

## Stainless Iron as an Engineering Material

The fact that this particular composition of chromium and iron has received the designation "stainless iron" has caused many to overlook the fact that it is something more than a corrosion-resisting metal. In reality it possesses remarkable physical properties which make it also an excellent engineering material. In its annealed state its typical physical properties are as follows:

| | |
|---|---|
| Ultimate tensile strength, lb. per sq. in... | 72,000–85,000 |
| Elastic limit, lb. per sq. in. | 40,000–50,000 |
| Elongation in 2 in., per cent | 32–37 |
| Reduction of area, per cent | 70–78 |
| Brinell number | 140–170 |

Despite the low carbon content it may be heat-treated to show maximum physical properties as follows:

| | |
|---|---|
| Ultimate tensile strength, lb. per sq. in. | 178,000 |
| Elastic limit, lb. per sq. in. | 161,000 |
| Elongation in 2 in., per cent | 15 |
| Reduction of area, per cent | 51 |
| Brinell number | 360–370 |

In this fully hardened condition the metal is not machinable. Our best recommendation for physical properties that will best meet engineering requirements is the following:

| | |
|---|---|
| Ultimate tensile strength, lb. per sq. in.. | 110,000–120,000 |
| Elastic limit, lb. per sq. in. | 90,000–100,000 |
| Elongation in 2 in., per cent | 23 |
| Reduction of area, per cent | 69 |
| Brinell number | 225 |

Attention is called to the exceedingly high elongation and reduction combined with such relatively high ultimate tensile strength.

For any definite heat treatment the physical properties can be predicted probably with greater accuracy than is the case with any other alloy. An additional characteristic of this material that makes it particularly suited for certain engineering applications is its high tensile strength at elevated temperatures.

For example, at 1000 deg. fahr. the ultimate tensile strength is 30,000 lb. per sq. in., at 1400 deg. this figure is 11,500 lb.; at 1800 deg., 7700 lb., and at 2000 deg., 4000 lb. Accompanying these high physical values at elevated temperatures is a marked resistance to scaling at temperatures not in excess of 1500 deg. fahr.

Ascoloy 33 is an air-hardening alloy and if worked at temperatures above its upper critical point, 1500 deg. fahr., it must be annealed before subsequent machining operations can be performed. It will be seen, therefore, that if the material is hot-worked by either rolling, forging, or pressing operations, an anneal or draw is essential for subsequent machining. This annealing may be accomplished by heating slightly above the upper critical point and cooling very slowly—not in excess of 50 deg. per hour. A full anneal, however, is not essential or desirable for best machining qualities, and the treatment recommended is a semi-anneal, or to be more accurate, a draw, at a temperature of from 1400 to 1450 deg. fahr., followed by an air quench, after which machining can be done readily.

### Uses to Which Stainless Iron Is Specially Adapted

The combination of corrosion resistance, workability, and high physical values gives the metal a general utility in industry perhaps not comprehended by those not perfectly familiar with its many applications. Therefore some of the most likely uses are listed here:

- Turbine blading
- Pump rods
- Pump impellers and casings
- Pipe and tubing, for surface or subsoil service
- Valve trim for valves handling corrosive liquids, oil, etc.
- Tie rods
- Bolts and nuts
- Tank plates
- Rivets
- Condenser tubes
- Superheater tubes
- Valve parts on ammonia pumps, caustic pumps, etc.
- Nitric acid manufacturing and storage equipment.

As a matter of fact, Ascoloy 33 is indicated for all applications where excessive corrosion is objectionable but where surface beauty is not essential.

### Super Stainless Iron

Several years ago there was developed in Germany, and at about the same time in England, a modified stainless iron, or rather, a super stainless iron. It was called by the Krupps in Germany, who first made it, V-2A Steel, and by the English makers, Stabrite. The latter designation is perhaps as descriptive a word for the alloy as could be coined. In this country, the first commercial producer of the alloy under the Strauss patents was the company with which the author is connected. By them it has been developed to a degree far beyond anything that has been done with it abroad.

Allegheny Metal, as this product is designated, is an alloy of chromium, nickel, and iron, containing from 17 to 20 per cent chromium and from 7 to 10 per cent nickel. Carbon, manganese, silicon, etc., are of course present, but only as technical impurities.

For many years, nickel-chromium alloys of the type of Nichrome have been in common use. Their range of usefulness has been well established. In the developmental work connected with the making of V-2A and Stabrite, however, a new series of alloys was studied in the chromium-nickel series. Generally speaking, the nickel-chromium alloys or those in which the nickel predominates are heat-resisting, while the chromium-nickel are primarily corrosion-resisting, this being especially true of the composition under consideration. It might be added that there are also heat-resisting alloys in the chromium-nickel series, obtained by increasing the chromium content to 22 per cent or more while keeping the nickel content at from 8 to 10 per cent.

The alloy in question is a super corrosion-resisting material and is believed to be the most highly developed metal for controlling corrosion that is available commercially. It is specifically recommended for applications where surface beauty and permanence of surface are essential. Containing no copper, it cannot corrode with the formation of the well-known verdigris. Its use is recommended where a metal of the strength of steel is required but where stainless iron cannot be used on account of its susceptibility to surface corrosion.

Allegheny Metal is an austenitic steel and therefore not susceptible to heat treatment. In its annealed condition it is non-magnetic to an extent never before obtainable with a ferrous alloy. It is ductile and malleable and therefore capable of being formed, stamped, and drawn. During cold-working operations the metal hardens, and in the woik-hardened condition it is magnetic. Annealing, however, at a sufficiently high temperature causes the reversion of the metal to its non-magnetic state. It is readily weldable, using welding sticks of the same composition as the metal to be welded, and the welds when made properly are ductile and malleable. It does not machine as readily as carbon steel or as Ascoloy 33, but compares in that respect with the well-known 30 per cent nickel steels.

### Physical Properties Imparted by Working Rather than by Heat Treatment

The fact that Allegheny Metal cannot be heat-treated to impart definite physical properties does not preclude obtaining any physical properties within the possible range. They must be imparted, however, through cold or hot working rather than through heat treatment. To illustrate this point, a typical example is given. In the annealed condition the alloy has an ultimate tensile strength of 90,000 lb. per sq. in. with a yield point of 45,000 lb. per sq. in., a true elastic limit of 30,000 lb. per sq. in., an elongation in 2 in. of 61 per cent, and a reduction of area of 75 per cent. When working specifically to produce the material for engineering applications the ultimate tensile strength should be 120,000 lb. with a yield point of 86,000 lb., a proportional limit or true elastic limit of 68,000 lb., together with an elongation in 2 in. of 36 per cent and a reduction of area of 52 per cent. It should be borne in mind, however, that the alloy is no more resistant to corrosion in its work-hardened condition than when annealed. As a matter of fact, it is very doubtful if the corrosion resistance of the annealed material is not superior to that of the work-hardened material.

In the drawing of Allegheny Metal, considerably more press power is necessary than in the drawing of similar shapes from steel, due entirely to the work hardening of the material. Therefore, more frequent annealings will be necessary. For example, a sample 0.078 in. thick showed a tensile strength in the annealed condition of 88,000 lb. per sq. in., with a yield point of 42,000 lb. and an elongation in 2 in. of 68 per cent. When this same sample was cold-rolled to 0.049 in. thick the tensile strength had been increased to 158,000 lb. with a yield point of 153,000 lb. and an elongation in 2 in. of 18 per cent. These figures make obvious the reason for frequent annealings in the cold working of the material.

Regarding annealing, it might be mentioned that the material begins to soften at temperatures from 1500 deg. fahr. The higher the annealing temperature is above 1500 deg., the softer the material becomes, provided the maximum annealing tem-

perature does not exceed 2200 deg. It has been found that material which has been work-hardened to the extent that it has become strongly magnetic can only be brought back to the non-magnetic condition by an annealing temperature in excess of 1800 deg. With this particular material the softness is a direct function of the annealing temperature.

### Properties at High Temperatures

In common with other corrosion-resisting metals, the alloy has rather remarkable physical properties at elevated temperatures, as is evidenced by the fact that at 1650 deg. fahr. an ultimate tensile strength of 25,500 lb. is obtainable, while at 1832 deg. it is 16,900 lb. and at 2012 deg. decreases to 11,300 lb. It will be seen, therefore, that Allegheny Metal has considerably more tensile strength at elevated temperatures than has Ascoloy 33. It is not recommended, however, for use at temperatures in excess of 1700 deg.

The material has an advantage over other corrosion-resisting materials in the matter of weight. In sheet form, for example, it is from 12 to 15 per cent lighter than monel metal, 7 per cent lighter than Tobin bronze, 11 per cent lighter than nickel-silver, 15 per cent lighter than copper, and 12 per cent lighter than nickel. From the standpoint of surface area, therefore, there is a considerable saving in weight to be effected through the use of this material.

The fact that it is a material of stable surface under normal corrosive influences, makes possible the use of the metal for applications involving contact with food products. It is an approved material for use in the dairy industry and imparts no taste or flavor to dairy products, nor is it attacked by these dairy products.

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# The Use of Pulverized Coal in Basic Open-Hearth Furnaces

By E. L. HERNDON,[1] POTTSVILLE, PA.

*The experience of The Eastern Steel Company with pulverized coal as fuel for basic open-hearth furnaces was anything but voluntary. The company had been very happily using oil which was low in price and high in quality, when the cost of this fuel began to rise and continued until it was necessary to cease using it. Since then, for thirteen years the company has continuously wrestled with the problems arising in the development of a little-known fuel. At times it has been more than willing to abandon the entire plan. Very little working knowledge was gained before the war period, and during the war costs were of less consequence than ordinarily. After that period passed, however willing the company was to alter the design of its furnaces and change the fuel, the necessary capital was never available. After many tribulations and at times successive disappointments, some understanding of the subject has been reached, and it is believed that pulverized coal is the best fuel for conditions as they exist. It is not recommended on that account, however, that others adopt pulverized coal until a thorough examination of each situation has been made.*

THE use of pulverized coal in the basic open-hearth furnaces of The Eastern Steel Company came about as the result of a continued advance in the price of fuel oil. This paper is an account of the experience of the company in dealing with a fuel of which there was no history to serve as a guide. The company has not maintained a research department and it is not intended to consider the subject from a scientific viewpoint. The work has at all times been empirical, and no exhaustive analysis of the results has so far been undertaken.

When The Eastern Steel Company began to make steel, the open-hearth department consisted of four 50-ton basic furnaces. Fuel for these was supplied by gas producers of the hand-poked type.

From 1905 until 1910 only producer gas was used, but during 1910 it was possible to make a contract for suitable fuel oil at two and one-half cents per gallon, delivered. This contract extended over two years. From its expiration until late in 1914 the cost of oil steadily advanced until it became prohibitive. During the period last mentioned, two 80-ton furnaces were designed and built. The designers considered only fuel oil and gave no thought to the possibility of returning to producer gas. When, because of increasing cost, it became necessary to abandon oil, it was apparent that additional producer equipment would be necessary in order to operate the two 80-ton furnaces, and also considerable change in the design of the furnaces would have been regarded as desirable. In this situation the attention of those operating the open hearth was directed to pulverized coal. This seemed, at the time, to offer considerable inducement, as the only change in the furnaces which seemed to be necessary was to replace the checker-chamber bricks with a series of arches, and provide burner equipment. These changes and additions were made, and since that time pulverized coal, with oil for an emergency alternative, has been used. A layout of the plant is shown in Fig. 1.

The open-hearth-furnace plant consists of four 50-ton furnaces and two 80-ton furnaces. All have basic bottoms, all are stationary, and all are of the ordinary design which was approved at the time they were built, and very few changes have been necessary.

When the pulverized coal was first used in the furnace, it was found that the checkers were filling up with ash. It was realized that this could not be prevented, and therefore arches were substituted for the checkers because of the greater space. The arches are placed about 18 in. apart in rows, one above the other, with about three feet between the rows.

The furnaces are reversed by two dampers, one placed in each flue between the checker chamber and the stack. This gives the products of combustion a direct path to the stack.

The slag pockets are equipped with removable structural-steel boxes which fill up in about fifteen days. The time ordinarily required to pull two boxes and get the fuel on the furnace again is about five hours.

The boxes used for the 50-ton furnaces are 15 ft. by 10 ft. by 2 ft. 5 in. deep; for the 80-ton furnaces, the dimensions are 18 ft. by 10 ft. by 2 ft. 5 in. All four sides of these boxes are tapered, and the boxes are lined with a 9-in. lining of old bricks laid up in common clay.

Each furnace is supplied with two storage bins for pulverized coal which have capacity sufficient to operate a 50-ton furnace for eighteen hours and an 80-ton furnace for fifteen hours.

The coal is supplied to the furnace from the bins by compressed-air siphons. On the 50-ton furnaces the air jet is $^3/_8$ in. in diameter and on the 80-ton furnaces, $^9/_{16}$ in. in diameter. The air pressure used is 80 lb. per sq. in.

Each furnace is supplied with the necessary equipment for using fuel oil in case of emergency. The oil supply is stored in the usual way, in a tank of considerable capacity, and is at all times on tap.

The plant for pulverizing the coal is situated near the end of the open-hearth building. See Fig. 1.

Preparation of the coal consists of crushing, drying, and grinding. At various times lump and run-of-mine have been used, and just now slack is being used.

The equipment consists of three Raymond five-roller mills and one Raymond four-roller mill. Each mill is connected to a motor. There are in addition two Cummer driers and one Jeffrey single-roll coal crusher.

When the coal is received, the railroad car is placed over a pit and the load dumped into the pit. From this it is hoisted to the top of the building, a height of about one hundred feet, by an Otis automatic dump-bucket elevator. There are two buckets, which are operated in the manner of the usual blast-furnace skip.

When it reaches the top of the skip, the coal is dumped into a storage bin which has a capacity of about two carloads; thence it passes to the crusher, located directly below the bin. When it has been crushed, it is dropped into another bin for storage before sending it to the driers.

The compartments for storing dried coal are quite small because it is thought unsafe to keep any considerable quantity of dried coal in storage. Each storage compartment is situated directly over one of the pulverizing mills, and the height of the

[1] Receiver, The Eastern Steel Co.

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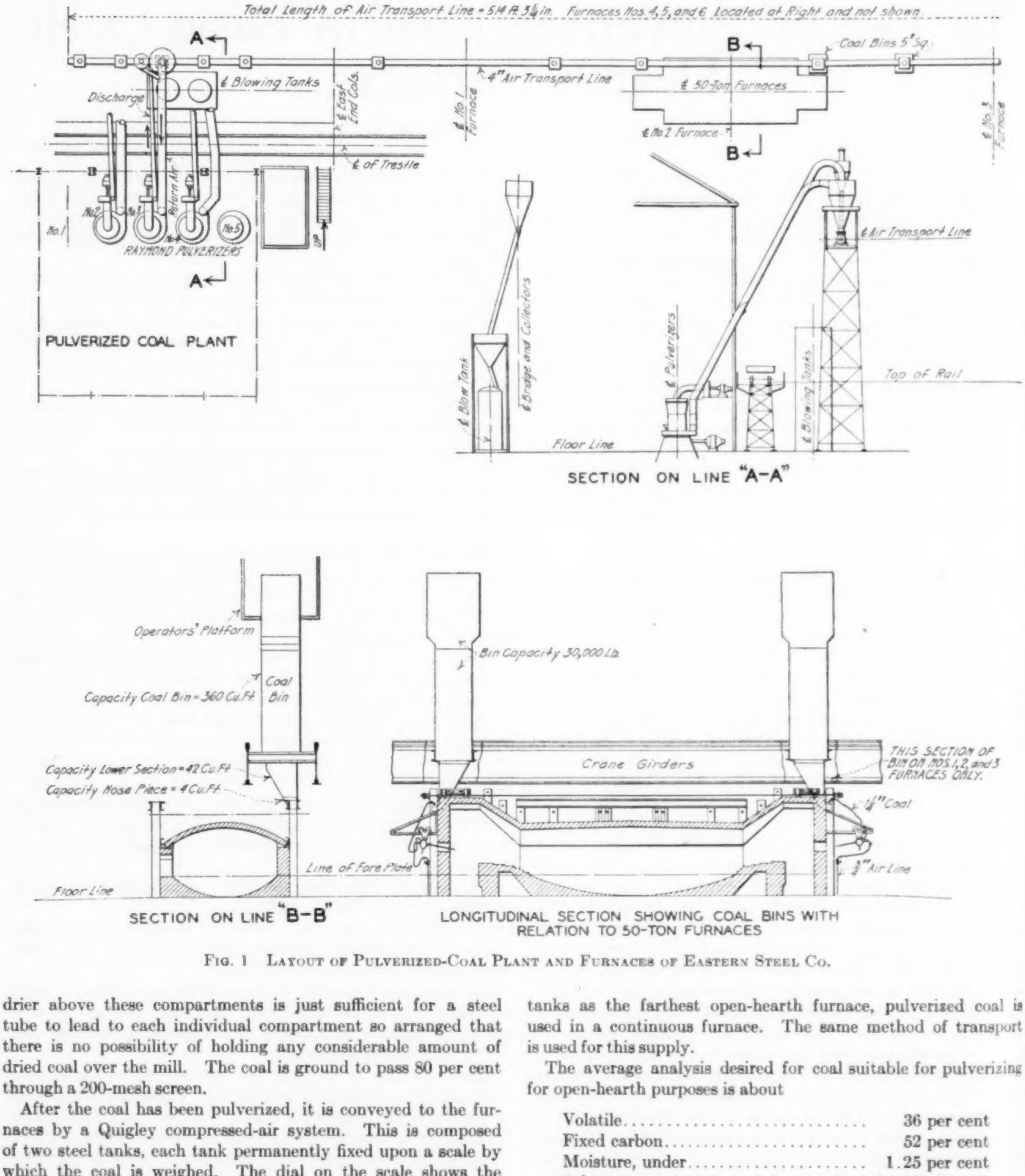


Fig. 1 Layout of Pulverized-Coal Plant and Furnaces of Eastern Steel Co.

drier above these compartments is just sufficient for a steel tube to lead to each individual compartment so arranged that there is no possibility of holding any considerable amount of dried coal over the mill. The coal is ground to pass 80 per cent through a 200-mesh screen.

After the coal has been pulverized, it is conveyed to the furnaces by a Quigley compressed-air system. This is composed of two steel tanks, each tank permanently fixed upon a scale by which the coal is weighed. The dial on the scale shows the amount of coal in the tank when it is being filled, and also shows the amount when the coal is being discharged, so that the readings show the weight of the amount taken to the furnaces. Compressed air is used for transporting the pulverized coal through a 4-in. pipe which connects the tanks just mentioned with the coal boxes over the furnaces. The distance from these tanks to the box at the farthest furnace is 450 ft. Each furnace supply box is furnished with a valve so that any box may be refilled as needed.

At a 12-in. mill located at about the same distance from the tanks as the farthest open-hearth furnace, pulverized coal is used in a continuous furnace. The same method of transport is used for this supply.

The average analysis desired for coal suitable for pulverizing for open-hearth purposes is about

| | |
|---|---|
| Volatile | 36 per cent |
| Fixed carbon | 52 per cent |
| Moisture, under | 1.25 per cent |
| Ash | 6 to 8 per cent |
| Sulphur under | 1.25 per cent |

The operation of the open-hearth furnaces does not now present more difficulty than with producer gas, though it is not as simple as with oil. All-cold charge is used, and the time for charging is about four hours. The scrap here is, in general, quite light and the percentage of pig is kept as low as possible because of cost; one heat in twelve hours is considered as 100 per cent, and it is usually possible to keep fairly near this through the campaign. The life of furnaces is about 200 heats for one roof. Usually a

second roof can be put on without disturbing any other part of the furnace, and then an additional 100 to 150 heats can be obtained with this second roof.

The coal required runs as low as 500 lb. and as high as 600 lb. per ton of ingots. The wide variation is partly due to character of coal, partly to the charge, to the analysis required in the product, and a little to the age of the furnace, although the time from tap to tap varies less than was formerly thought possible. The temperature maintained in the furnaces is essentially the same as that with producer gas.

There have been infrequent explosions, one in which one life was lost and considerable damage to property resulted. The others were not of consequence. The cause of the serious explosion is not known, although reasonable theories and some conjectures are held, but no proof. The experience during thirteen years does not seem to indicate extra-hazardous occupation.

Experience with pulverized coal has convinced the company that very little has been learned, certainly no more than has been included in this paper. Comment and criticism from those who are interested are invited. If engineers interested in the subject care to visit the plant, they will be welcomed.

## Discussion

C. D. Northam.[2] After reading the very interesting paper by Mr. Herndon, detailing the experience of his company with powdered coal in firing open-hearth furnaces, the writer was curious to know just what this 500 to 600 lb. of coal per ton of ingots represented.

Taking the average analysis of coal used, it is evident that the constituents do not total 100 per cent, and it is assumed that the moisture given is "after drying," while the remainder of the analysis is "as received." Rearranged, we would have the following analysis, after correcting moisture:

| | Proximate analysis | Combustible |
|---|---|---|
| Volatile, per cent | 36.00 | 40.30 |
| Fixed carbon (and sulphur), per cent | 53.25 | 59.70 |
| Ash, per cent | 7.00 | .... |
| Moisture by difference, per cent | 3.75 | .... |
| Total, per cent | 100.00 | 100.00 |

If we calculate the ultimate analysis from the above proximate analysis, the following results are obtained:

| | |
|---|---|
| Hydrogen, per cent | 4.78 |
| Nitrogen, per cent | 1.44 |
| Carbon, per cent | 73.15 |
| Sulphur, per cent | 1.25 |
| Ash, per cent | 7.00 |
| Moisture, per cent | 3.75 |
| Oxygen, per cent | 8.63 |
| Total, per cent | 100.00 |

From this analysis, by Dulong's formula, the calorific value of the coal used is found to be:

$$h = 14{,}544\,C + 62{,}028\left(H - \frac{0}{8}\right) + 4050\,S$$

$$= 14{,}544 \times 73.15 + 62{,}028\left(0.0478 - \frac{0.0863}{(8)}\right) + 4050 \times 0.0125$$

$$= 12{,}985 \text{ B.t.u. per lb. of coal as received.}$$

Correcting for the maximum allowable moisture in coal as fired, the calculated heat value of coal used is:

[2] Mechanical Engineer, Chicago, Ill. Jun. A.S.M.E

$$\frac{12985}{0.975} = 13{,}318 \text{ B.t.u. per lb. of coal as fired.}$$

Using this result, it is evident that the heat rate per ton of ingots, using powdered coal as fuel, in a basic open-hearth furnace varies from

$$500 \times 13{,}318 = 6{,}659{,}000 \text{ B.t.u. per ton}$$

to

$$600 \times 13{,}318 = 7{,}990{,}800 \text{ B.t.u. per ton}$$

or an average of 7,324,900 B.t.u. per ton of ingots. As this is several million B.t.u. higher than good average practice using oil as fuel, the question arises, "Where do these extra heat units go?" The writer believes an analysis of existing stack and regenerated air temperatures would show this; at least, it would be interesting to know what temperatures are obtained using these arch-work generators.

E. W. Wagenseil.[3] Regarding the application of powdered coal to open hearths, the writer would ask if the author has any data available as to air temperatures at the top of the checkers—of the air that was preheated; and also what percentage of the total air was preheated and what percentage entered as old air around the burner. Also, if temperatures were taken of the heated air, were they taken with an aspiration pyrometer or with just an ordinary thermocouple? Finally, what percentage of oxygen was found in the flue gas?

It would seem apparent that with arches substituted for the checker bricks, the air temperature could not have been very high. In that case a modern air preheater heating the air to, say, 1000 deg. fahr. before the air entered the checker chambers might result in a marked reduction in fuel required per ton of steel made.

I. A. Nicholas.[4] The Clairton plant of the Carnegie Steel Company has had about three years' experience in the use of powdered coal in open-hearth furnaces. The reason for using it was a shortage of natural gas; therefore it was a temporary proposition, and as soon as the coke-oven plant was installed, the furnaces were changed over to coke-oven gas instead of returning to natural gas.

It has been ten years since the powdered coal was used, and the writer's memory is not very distinct on all phases of the experience with it. However, it is recalled that the fuel consumption was 500 to 600 lb. per ton of steel and the life of the roofs was about 200 heats.

G. E. Heine.[5] A very important question in connection with the application of powdered coal to take the place of fuel oil for reheating furnaces of the regenerative type is that of ash disposal. A unit pulverizer operated very successfully in a certain plant for the first few days. Then, although the checker chamber were cleared of all checker brick, they still continued to fill up with ash. It was found that this ash, under the action of the hammer or the press, became imbedded in the surface of the steel.

A few rough operating calculations produced results that may prove interesting. They showed that for one dollar with powdered coal, unit pulverizer system, including the cost of the current, 1407 lb. of steel was heated, whereas with fuel oil it was only 558 lb. It would seem that there should be an opportunity to make a saving from the fuel standpoint but for the ash.

It would be of great interest to the writer to have a word from

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[4] Fuel Engineer, Carnegie Steel Co., Clairton, Pa.

[5] Power Engineer, Erie Forge & Steel Co., Erie, Pa. Mem. A.S.M.E.

some one who has met this problem of the handling of the ash and the effect of the ash on the steel.

W. P. Chandler.[6] Attempts have been made in firing open-hearth furnaces with pulverized coal to grind the coal particularly fine, the idea being that the resultant ash would be fine enough to be carried out of the furnace and through the flues by the velocity of the exit gases. In order not to interfere with this action, the checkers were removed. However, a continual building up has taken place in the chambers, and the loss of preheat in the air caused by the removal of the checkers has been reflected in the fuel consumption of the furnace.

The figures of 500 to 600 lb. per ton of ingots as given by Mr. Nicholas are common.

H. W. Brooks.[7] This matter is in a research stage. It may serve a useful purpose; we do not know. We want a contribution of experience so that the things which were foolishly done ten years ago will not be repeated, and it is the writer's belief that the experience which has been developed at Pottsville and the experience developed by the Atlantic Steel, plus the experience of Homestead and Clairton, if properly correlated, would form a nucleus for some useful developmental work along this line.

None of us think we have the answer—we haven't. We do not know whether what we have is worth while or will prove to be the proper thing or not, but attention is called to the figures given by Mr. Heine, showing operating economies in the relation 558 to 1407. Are we going to say it cannot be done because it never has been done, or will we take a research attitude of mind and see what we can do? Shall we go as far as we can and see how far we can go?

That is all we are trying to do in this whole situation, and it is only with the helpful cooperation of all interested in the problem that the ultimate result to be desired will be brought about.

[6] Manager, American Heat Economy Bureau, Inc., Pittsburgh, Pa.

[7] Consulting Engineer, New York, N. Y. Mem. A.S.M.E.

# Recent Developments in the Use of Nickel Steels

By CHARLES McKNIGHT,[1] NEW YORK, N. Y.

*After recounting the early uses of nickel steel for armor plate, guns, and projectiles, the author deals at some length with the development of its use in locomotive construction for heavy forgings and later for the shell plates of high-pressure locomotive boilers. He then touches briefly on three recently developed iron-nickel alloys—Invar, Permalloy, and Nickeloy—the latter two being employed extensively in electrical work, and with the substitution of nickel-chrome-steel castings for those of manganese steel in trackwork. He concludes with a statement of the advantageous properties conferred on cast iron by the addition of nickel.*

IT IS THE scope of this paper to cover very briefly uses for nickel steels (and other nickel-iron alloys) which for their size, manner of treatment, or properties are new or unusual. There is already complete and adequate information on the manufacture, heat treatment, and use of these steels as ordinarily employed, but it might be of value to sketch the history of nickel steel and define its position today.

The origin of nickel steel lies back beyond history, because all meteors are essentially nickel steel, but the first recorded use was in the Middle Ages when some of the famous Damascus swords are known to have contained nickel. In 1821, after a gap of centuries, Faraday, searching for a better material for mirrors, investigated the properties of "meteoric irons." In 1885 the commercial manufacture of nickel steel was begun in France, and in 1889 Riley read his paper on this subject before the Iron and Steel Institute.

## Early Uses of Nickel Steel

This began the real growth. Creusot in France made some $3^1/_2$ per cent nickel-steel armor plate, which demonstrated its superiority so conclusively that in 1890 the United States Navy adopted it for armor after a conclusive and competitive test. Authorities state that the adoption of nickel steel for armor plate was as revolutionary as the construction some twenty years later of the "Dreadnought."

By 1896 nickel steel was being quite widely used—in naval vessels, for guns, armor plate, and projectiles, in heavy machinery, to a limited extent on the railroads, and quite largely for bicycles. The development of the automobile helped the growth, and from 1900 on till after the war the production curve mounted steadily.

It may be truthfully said that nickel steel is not only the oldest alloy steel but the most used. An idea of its widespread employment today can be gained from the fact that every automobile uses some nickel steel—the amount running from 1500 lb. per car down to a few pounds. This preponderance toward nickel steels is in great part due to two characteristics that are almost unique among alloying materials: nickel alloys with iron in all proportions, and there is no loss of the alloy during melting. The latter fact renders its manufacture more exact as well as more economical initially, because less alloying material is used and eventually because the nickel in scrap can be fully recovered on remelting. Nickel, once purchased, is never lost.

## Nickel Steel in Locomotive Construction

One of the first uses for which nickel steel was employed was in locomotive construction, and yet until recently the development has lagged. It is generally admitted that there is no greater field for alloy steel at the present time than the railroads, which use very little in proportion to the total tonnage of steel employed. The reason for this is, of course, that in the first place the railroad shops have not, for good reasons, kept pace with the automotive industry in being equipped and educated to handle and heat-treat alloy steels, and, second, because about fifteen or twenty years ago, following the success of the alloy steels in the automobile, the railroads were induced to adopt similar steels for their purposes. It is manifestly ridiculous to compare the rear-axle shaft of an automobile to the massive driving axle or main rod of a locomotive, but the mistake was made of recommending the same steels treated in a similar way. So many failures ensued that for years the railroads were unwilling to consider the use of anything which might be considered an alloy steel, but beginning about 1915 and increasing each year they began to use frames and forgings which were alloy steels in the sense that they carried a percentage of alloying elements, but were not alloy steels in the sense that they were not intended to be heat-treated other than by normalizing or annealing.

In the development of locomotive parts the tendency has been to higher and higher tensile strengths. Taking locomotive driving axles for example, wrought iron was originally used with an ultimate tensile strength of about 45,000 lb. per sq. in. This was later replaced by carbon steel with an ultimate tensile strength of 75,000 lb. per sq. in., and carbon steel in turn has quite generally given away to alloy steel with a tensile strength of 90,000 lb. per sq. in. or higher. It has perhaps been natural to reason that if failures occur with one material a stronger material will obviate the difficulty, and it has been this reasoning which has induced the railroads to use steels of higher and higher strengths.

The logic of this reasoning can be questioned, and it seems that too much attention has been paid to strength and not enough to other characteristics, such as the reduction of area, elongation, impact, and fatigue values. The practical limit of strength, however, has now been reached for normalized forgings, and as it seems to make no difference what alloy is used, it is not possible greatly to increase the strength over that now being reached. As the strength of the steels employed has been progressively raised, so has the carbon content. Wrought iron, of course, contains comparatively little carbon; the steels in use today run in the neighborhood of 0.45–0.50 per cent carbon.

In the present dilemma recourse has been had to the other extreme, and comparatively low-carbon (0.15–0.30) nickel steel has recently been used and is being favorably considered as a material for the stressed forgings on locomotives. Such a material will show an elastic limit of 55,000–60,000 lb., an ultimate tensile strength of 70,000–90,000 lb., with unusually good elongation and reduction of area—about 26–35 per cent and 50–70 per cent, respectively. These data compare with those specified for the usual alloy-steel forgings of 60,000 lb. elastic limit, 90,000 lb. ultimate tensile strength, 20–25 per cent elongation, and 40–50 per cent reduction of area, so that with a slight reduction in strength the toughness factors have been increased

[1] Development and Research Department, The International Nickel Company.

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about 25–30 per cent. It is interesting to note that the impact value for very low-carbon 3.5 per cent nickel steel is approximately 50-lb. Izod against the average of about 18–20 for normalized alloy-steel forgings of high carbon (0.40–0.50) content, and the fatigue limit is about 50,000 lb. per sq. in., which is relatively much higher than for steels now used.

## Nickel Steels Important in Railroad Use for Forging Work

These nickel steels may be of several analyses, the choice depending on economical considerations and what properties are desired. The three which are most important in railroad use

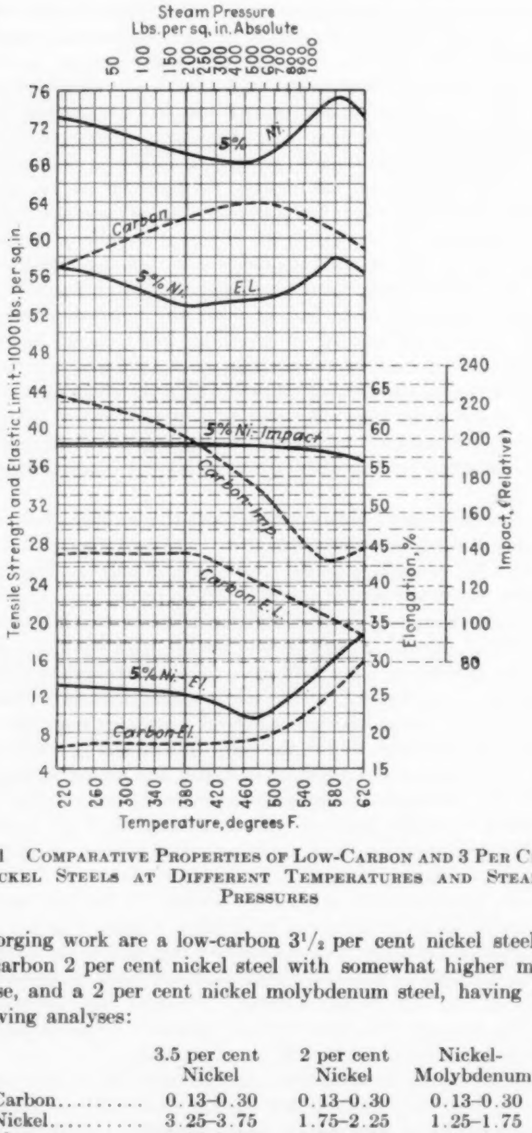


Fig. 1 Comparative Properties of Low-Carbon and 3 Per Cent Nickel Steels at Different Temperatures and Steam Pressures

for forging work are a low-carbon $3^1/_2$ per cent nickel steel, a low-carbon 2 per cent nickel steel with somewhat higher manganese, and a 2 per cent nickel molybdenum steel, having the following analyses:

| | 3.5 per cent Nickel | 2 per cent Nickel | Nickel-Molybdenum |
|---|---|---|---|
| Carbon | 0.13–0.30 | 0.13–0.30 | 0.13–0.30 |
| Nickel | 3.25–3.75 | 1.75–2.25 | 1.25–1.75 |
| Manganese | 0.60–0.90 | 0.90–1.25 | 0.60–0.90 |
| Silicon | 0.15–0.25 | 0.15–0.25 | 0.15–0.25 |
| Phosphorus | Max. 0.05 | Max. 0.05 | Max. 0.05 |
| Sulphur | Max. 0.05 | Max. 0.05 | Max. 0.05 |
| Molybdenum | ....... | ....... | 0.15–0.25 |

All of these steels are commercial and each has its reason for use. The 3.5 per cent nickel steel shows rather remarkable properties, especially as regards toughness and impact resistance when used in the lower carbons; the nickel-molybdenum owes its slightly higher tensile results for a given carbon to the addition of molybdenum, although this makes the steel a little more difficult properly to heat-treat; the 2.0 per cent nickel steel has the advantage of being cheaper, yet with very good properties, and is the most used of the three today.

Low-carbon nickel steel is peculiarly suited for axles and pins. It appears that no matter how careful the operation of a railroad or how much warning is given to the engineman, journals and pins will occasionally run hot, and it is not uncommon for them to be cooled with water from the tender—in fact it may be noticed that quite a large number of locomotives are equipped with pipes running to the journals. Such a practice involves real punishment for any steel, and it is not difficult to understand the large number of axle failures which result from it, especially when it is realized that quite frequently the axles are allowed to get red enough to be seen in daylight (about 1200 deg. fahr.) before they are quenched by putting cold water on them. It is not reasonable to ask any steel to stand up under this treatment, but the low-carbon nickel steel has shown better results than any other and does not crack or heat-check to anything like the extent that other steels do.

While the steels mentioned have been treated with particular regard for their employment in locomotives, it should be observed that they are equally suitable in machinery of any sort where forgings of such size as to preclude heat treatment are necessary. Such uses are large shafts, connecting rods, turbine rotors, gears, etc.

The development of forging steels for locomotives has been duplicated in regard to frames. They were originally wrought iron and were then replaced by steel castings and the steel castings replaced by alloy-steel castings—always in search for higher strengths. Railroad operators state that any frame seems to be good for five to seven years, after which failures start. Occasionally when a frame fails it does so in as many as 15 places at one time, all showing true fatigue conditions. In spite of this, the tensile requirements have been raised so that the foundries are now working to a specification of 50,000 lb. elastic limit, 80,000 lb. ultimate tensile strength, 20 per cent elongation, and 40 per cent reduction of area, which characteristics are, by the way, higher than those of the regular specifications of the American Society for Testing Materials for carbon-steel forgings.

When nickel steel was adopted for locomotive frames, the present specifications were easily met with steel containing 3 per cent nickel and 0.35 per cent carbon, but it was soon realized that all advantages seemed to lie in the other direction. Obtaining permission from the railroad, the foundry was instructed to lower the carbon gradually, and it was eventually found feasible to produce with only 0.18 per cent carbon and 2 per cent nickel a frame casting showing (as an example of an actual frame) an elastic limit of 51,350 lb., an ultimate tensile strength of 83,850 lb., an elongation of 30.5 per cent, and a reduction of area of 55.9 per cent. Coupled with these data are an impact value as high as is obtainable even from a forging of the type generally used today, and a fatigue limit very nearly as high. Compared with a good carbon-steel frame casting, the fatigue limit for a nickel-steel frame is 45,000 against 32,000 lb. per sq. in., an increase of 41 per cent, and the impact value is 18.3 against 5 ft-lb., an increase of 366 per cent. It should be realized when these frames are considered that they are no small castings for a jobbing foundry, as the finished weight of a pair of frames for a locomotive is approximately 22,000 lb. and the total casting weight about 38,000 lb.

The conclusion drawn from this work on large nickel-steel forgings and castings is that nickel steel heat-treated by normalizing or annealing seems definitely to be better the lower the carbon, all things considered. The strength stays well up, while the factors indicative of toughness and resistance to impact

and fatigue are much better. It is doubtful whether this can be said of steels using alloys which confer their benefits through the formation of carbides.

### Nickel Steel for High-Pressure Locomotive Boilers

One of the most interesting and perhaps one of the most important of the newer developments is the use of nickel steel for steam boilers. For the past quarter of a century the improvements in locomotives have been along the lines of accessories which will make the operation more efficient. Such accessories are the superheater, the feedwater heater, the stoker, etc. During this period of time the steam pressure of the boilers has remained fairly constant at 150 to 200 lb. per sq. in. Recently, however, attention has been focused on this feature of pressure because the locomotive has reached a fairly high stage of development as well as because of the relatively greater efficiency which is obtained with the higher steam pressures. Perhaps no trend in the railroad field has been so definite recently as that toward higher boiler pressure, and today we have in this country several locomotives such as the *Horatio Allen* on the D. & H. which operate at a boiler pressure of 350 lb. per sq. in., and there are either planned or in the process of building some for pressures as high as 450–500 lb. Abroad the advance has been perhaps more rapid than in this country, and there are in use today locomotives with boiler pressures as high as 1100 lb. per sq. in.

The trend toward higher steam pressure is being hastened on account of the limitations in weight and size. Our forefathers, had they had the foresight to see the eventual development of the railways in this country, would probably have adopted in the beginning a wider gage for the tracks and would have built the fixtures along the right of way, such as bridges and tunnels, larger to accommodate the trains of the future. As it is, the railroad locomotive has very nearly reached the limit of size. It is of course out of the question to talk of increasing the gage of the tracks or rebuilding all the tunnels and other limiting structures along the right of way in order to make possible larger trains, and the bridges would have to be rebuilt and the right of way materially changed to carry any heavier loads.

Recently one of the important railroads on this continent, in designing new locomotives for both passenger and freight service, was faced by the conflicting demands for more power with no increase in weight. Their locomotives were already up to the limit of weight and size. The only solution, therefore, was in a higher boiler pressure with no increase in weight, which meant that the boiler would have to be constructed out of plate of the same thickness as before. After long deliberation they decided to take an unprecedented step in using a 3 per cent nickel steel in place of carbon steel for the boiler shell. It was not only an unprecedented step but a very venturesome one. True, nickel steel had been successfully used abroad for boilers, but never for railroad service or in a locomotive type of boiler. However, there were some features that made their course seem advisable. The ultimate tensile strength of the 3 per cent nickel-steel boiler plate is approximately 40 per cent higher than the ultimate tensile strength of the carbon-steel, while the elongation and reduction of area are practically the same. In other words, the nickel-steel plate was 40 per cent stronger with no diminution in toughness. This 40 per cent increase in strength made it feasible to increase the boiler pressure from the normally carried 200 lb. up to the desired pressure of 250 lb. without overstepping the limit of conservatism. As a matter of fact, it would have been possible to go as high as 275 lb. with the same or a greater factor of safety.

Equally as important as the tensile characteristic of the steel, although almost unknown, are the characteristics of carbon-steel and nickel-steel plate under actual conditions of use in a boiler. It has long been known by boiler manufacturers that static tests on material give no real indication of the suitability of boiler plates for service, and even the impact test on the plate as received is not a good guide. The reason for this is that plates which are entirely satisfactory in the raw undergo alterations during the manufacturing processes, or perhaps later while in operation, which make them brittle. The actual embrittling phenomena have been termed "aging" and "recrystallization." By the term "aging" is understood the change in the strength of the plate which takes place gradually after it has been stressed when cold beyond its elastic limit. This condition is shown by the reduction in the impact-test value as well as by the embrittlement of the material. The term "recrystallization" refers to the phenomenon which is produced through stressing the material while cold and then subjecting it to higher temperatures (such as in boiler service).

Practically, in a boiler the effects of either aging or recrystallization or both may occur because the plates are stressed during

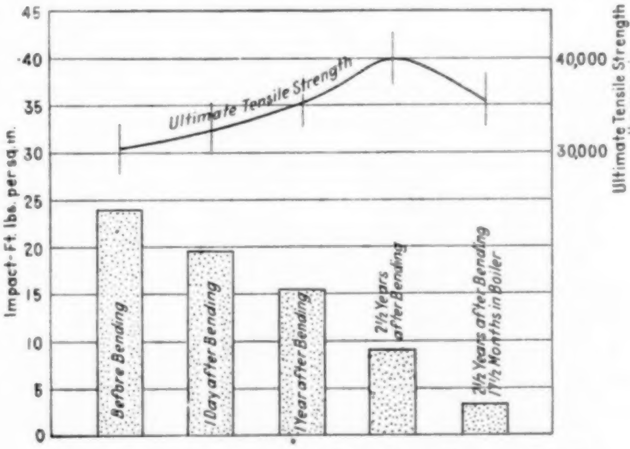


Fig. 2 Service Test of Carbon-Steel Boiler Plate
(C, 0.11; Mn, 0.53; P, 0.26; S, 0.31. Plate 0.8 in. thick by 22.5 ft. long, annealed before bending at 1685 deg. fahr.)

forming and bending in the manufacture of the boiler, or they may occur after the boiler is in commission as a result of temperature stresses which are induced by differences in the temperature at various parts of the boiler. The injurious effects will become more noticeable as the boiler pressure and consequent thickness of the plates increase because of the great difficulties of forming, bending, and riveting heavier plate, as well as because of the fact that increased heating surface and higher rates of evaporation offer more favorable conditions for temperature differences and additional stresses in the boiler.

It is here that nickel steel offers another distinct advantage over carbon steel. Fig. 4 shows the values of the impact test on carbon steel before and after aging and recrystallization, as well as those for nickel steel. It will be noted that where the carbon steel, after aging and recrystallization, shows only a small proportion of the original impact value, the nickel steel is affected only to a slight degree.

It must be remembered that the strength of a plate does not vary in direct proportion to the thickness. Therefore, to maintain the same factor of safety with higher boiler pressure using carbon-steel plate, the plate would have to be considerably thicker than indicated by the ratio of boiler pressures. This would introduce more liability to embrittlement through aging and recrystallization, because the effect is greater as the thickness increases. By the use of nickel steel it has been possible to use

higher boiler pressures with the same thickness of plate (and consequently the same boiler weight), with an actual increase in the factor of safety due to the lessened liability of embrittlement. This essentially amounts to saying that by substituting nickel steel for carbon steel the factor of safety was increased although the pressure was raised, but had the thicker carbon-steel plate been used the factor of safety actually would have been reduced considerably.

It was hard to predict before these locomotives were built just how effective they would be, although it was of course known that the theoretical drawbar pull would be increased by about 20 per cent. It was found when the locomotives were put in service that the actual drawbar pull was increased somewhere in the neighborhood of 10 per cent, and, as was expected, the factor which limited this actual drawbar pull was the adhesion of the driving wheels to the rails. In other words, had the wheels had sufficient adhesion it would have been possible to develop the full 20 per cent. The accelerating power of the locomotives was increased to a marked degree, as was the maximum speed. The superiority of the locomotives is succinctly expressed by the statement, "The new passenger locomotives will haul sixteen cars instead of fifteen cars ten miles an hour faster, and do it on the same coal used by the old locomotives."

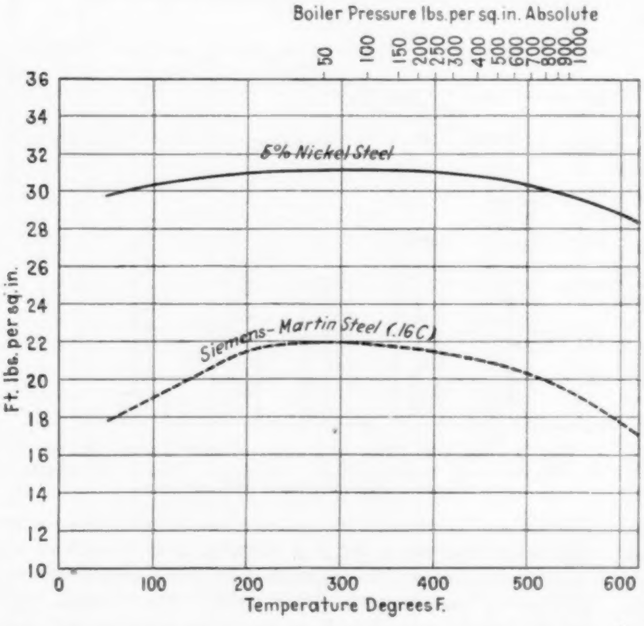


FIG. 3 IMPACT TESTS OF NICKEL- AND LOW-CARBON-STEEL BOILER PLATES AT DIFFERENT TEMPERATURES AND BOILER PRESSURES

The success of this new type of boiler is indicated by the fact that in this country two years ago there were not more than two or three nickel-steel boilers in existence or seriously contemplated, while today there are in service more than fifty nickel-steel locomotive boilers about equally divided between passenger and freight, and almost daily inquiries indicate increasing interest. This interest is not confined entirely to the locomotive field as the manufacturers of stationary boilers also appreciate the advantages of this material.

While not in any sense a consideration for the adoption of nickel steel for these boilers, a feature not to be overlooked was that of the increased resistance to corrosion of the nickel-steel boiler plate. There has always been considerable trouble, especially in bad-water districts, with firebox sheets. These sheets are exposed to the hardest service in a boiler due to the actual contact with the fire on one side and with the water on the other, together with the fact that they are perforated every few inches to carry staybolts. If the boiler feedwater is corrosive to any degree, it will start cracks around the staybolt holes, and these often develop into long cracks reaching up and down the whole side of a firebox. The use of a 3 per cent nickel-steel plate here shows markedly increased resistance to corrosion for the reason that the nickel in the steel confers a certain amount of immunity, as well as because the stresses around the staybolt holes do not affect the nickel-steel plate as severely as they do carbon steel. It is of course recognized that the corrosion cracks start where the steel has been stressed. It seems safe to say that a great deal of the trouble with these sheets will be obviated by its use, and the railroads which have adopted nickel steel for this purpose are apparently well satisfied.

For boiler tubes the situation regarding corrosion is exactly the reverse of that for shell plate as corrosion resistance is here the primary consideration and the increased strength has little to do with it. Boiler tubes running from 0.10–0.20 carbon and containing about 2 per cent nickel have shown in actual service a life of from seven to fifteen times that of carbon-steel tubes in districts where the water is bad. This of course has been sufficiently encouraging to warrant the standardization of nickel-steel boiler tubes in bad-water districts for the particular railroad quoted, and in addition there are a large number of railroads which either have nickel-steel boiler tubes under test or are using them as a regular material on some portions of their lines. Their use is not entirely new, as tubes with a higher percentage of nickel were used by several of the navies, among them our own, as long ago as 1900, and ones with a lower nickel percentage only a few years later. The unexplained peculiarity of these tubes has been the fact that boiler scale collects to a much less degree on them than on the ordinary tubes. It has been reported in at least one case where a boiler was tubed partly with carbon steel and partly with nickel steel, that the nickel-steel tubes outlived three sets of carbon-steel, and when removed were found to be in practically the same condition as when they came from the mill: that is, with the mill scale perfectly apparent.

Staybolts have customarily been made of wrought iron because they are subjected to very severe conditions of repeated bending as well as of corrosion. For several years an English concern has been substituting steel staybolts for iron ones with excellent results, and these results were attributed to the fact that the steel carried nickel. Recently in this country the steel staybolts have been encroaching very rapidly on the wrought-iron bolts, and practically all these steel bolts carry nickel, usually around 2 per cent but running down in some cases as low as 0.50 per cent.

## NOVEL EMPLOYMENT OF NICKEL-IRON ALLOYS

*Invar.* Considerable time has been spent on locomotives because they happen to include three new developments. Other forms of power are being improved by a novel employment of nickel steel, or, if it is preferred, an iron-nickel alloy. Invar, which is quite well known, consists of approximately 35 per cent nickel, the remainder essentially iron, and has been used for standards of length, measuring tapes, clock pendulums, etc., because its thermal coefficient of expansion at ordinary temperatures is practically zero (0.8 part per million per degree centigrade). Naturally, the quantity of Invar used for such purposes has been very limited, but this quantity has been increased many hundred per cent in the last two years through its use in automobile pistons and is almost worthy now of being designated as a tonnage. Aluminum (and other light alloys) for pistons in internal-combustion motors would have had a much more extended

use on account of the advantage obtained by lightening the reciprocating parts, were it not for the difference in thermal expansion between cast iron and aluminum. If the aluminum piston is made with the usual allowance for expansion, it will expand faster in use than the cast-iron cylinder and eventually bind and score the cylinder wall. On the other hand, if allowance is made in machining for this difference in expansion the piston will be too loose at low temperatures, where the automobile motor must necessarily operate frequently, and this will result in a piston slap. These difficulties are now remedied by casting into the aluminum piston two strips of Invar which hold the piston-pin bosses in place. The coefficient of expansion of the Invar being practically zero and that of aluminum about 15 parts per million per degree, it is comparatively simple so to place the right mass of Invar in order to make the average expansion of the compound piston equal to that of cast iron (about 11 parts per million). In addition, the strips of Invar prevent the scoring of the cylinder due to the piston's taking an elliptical shape from the straining action of the piston pin—a fairly common trouble.

*Permalloy.* Other high-nickel-iron alloys have, like Invar, been of more academic than industrial interest but are now increasing in use. There was discovered in the Bell Telephone Laboratories about the time of the war an alloy named "Permalloy" consisting of 78 per cent nickel, remainder iron, which, subjected to proper heat treatment, showed a magnetic permeability much higher than any known material. It was not used practically until after the war, but was then taken up by the Western Union as a material for increasing the working speed of its submarine cables. In 1922, after considerable experimentation during which the characteristics of the material were investigated at temperatures and pressures coinciding with those encountered in submarine telegraphy, 120 miles of cable were made with Permalloy sheathing and laid on the bottom of the ocean in a circle with both ends ashore at Bermuda. So satisfactory were the characteristics of this cable that the cable laid in 1924 to the Azores for connection to Italy and Spain was ordered to be sheathed with Permalloy, and this first transatlantic cable was in turn so successful that the latest cable to England laid in the past year was similarly constructed.

The cost of a cable of such length reaches so high in the millions of dollars that it is essential for economic operation to increase the speed to the maximum possible. However, on the old cables a speed of 300 words per minute was the maximum obtainable, and the majority of them cannot exceed 150 words per minute. The new cables were able to handle with ease 1500 words per minute and it is possible that they can go higher than this. The amount of Permalloy used in a transatlantic cable is both gratifyingly large and surprizingly low. The tape is wound spirally on the whole length of the cable but it is only 0.006 in. thick. Therefore, the banding in a transatlantic cable is a strip of Invar 0.006 in. × 0.125 in. × 61,000,000 ft. long. The total weight in the new transatlantic cable is only 30,800 lb., containing 24,640 lb. of nickel.

*Nickeloy.* The difficulties in manufacturing Permalloy, especially the heat treatment, have resulted in the development of another alloy containing 50 per cent nickel and known as "Nickeloy" (or "50/50"). This does not have quite as high a permeability as Permalloy, and it also is not as nearly as sensitive to heat treatment. In common with Permalloy it shows relatively a very much greater magnetic permeability at low field strength than at high. At field strengths such as those met with in communication work, both of these alloys show an enormous superiority over ordinary transformer-core materials, such as iron and silicon steel, as Permalloy is thirty times more permeable than ordinary transformer iron and its hysteresis curve covers $^1/_{16}$ of the area of that of iron. Such characteristics, coupled with the relative insensitivity of Nickeloy to heat-treating and stressing, as in punching, make it the core material par excellence for radio transformers for which it is now being more and more widely used as the demand for improved radio reception grows. The magnitude of this relatively unimportant field can be gaged by the fact that recently one concern alone was using daily 60,000 lb.—or two carloads of sheets—for radio-transformer cores.

The results obtained with this material for radio-transformer cores has caused investigation as to its suitability for power transformers. Here the field strengths are naturally much higher and at first glance it seems impossible to reconcile the permeability curve of the nickel-iron alloys with the demands of the power field. However, these alloys are now being used for one particular application—a current transformer for switchboard use—and it is not inconceivable that, by judicious designing, this material will be made available to the production and transmission of power. Obviously the present high price is a deterrent. If, however, nickel-iron alloys are used in much

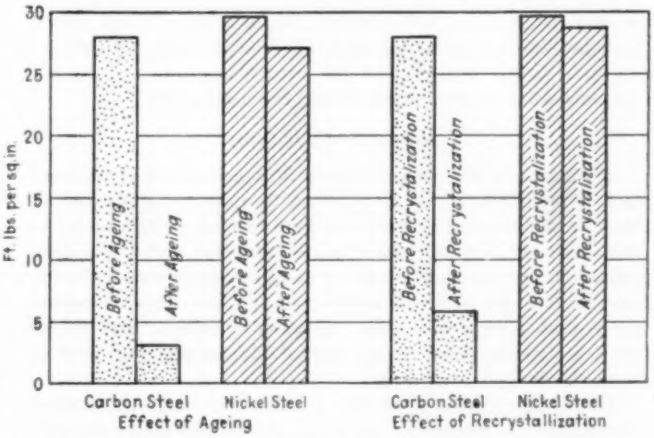


FIG. 4 AGING DATA ON LOW-CARBON AND NICKEL STEELS
(Carbon steel stressed under 36,000 lb. per sq. in. before aging; nickel steel under 61,200 lb. per sq. in. before aging.)

larger quantities the volume itself will reduce the cost. If the use of silicon steel for transformer cores in place of low-carbon steel or iron saved the power producers and consumers of this country $15,000,000 during 1925, as one authority states, there is ample incentive for the adoption of a core material that will still further reduce losses.

Ordinarily it would not seem logical to use the same materials for such opposite characteristics as maximum magnetic permeability and for non-magnetic qualities, but nickel steels are used for such things as the end plates and other parts of electrical generators, for switchgear, and for transformer components in order to avoid the induced eddy currents and other losses encountered if a magnetic material is used. The enforced installation by many of the railroads of automatic train-control apparatus opens up tremendous possibilities in this field. All existing types of train-control apparatus, as far as is known, employ a magnetic coil in a suitable housing along the right of way to influence the pick-up mechanism of the locomotive. These coils are placed every three-quarters of a mile or every mile, and there must be one for each track—which indicates the number eventually to be used. It is essential that these cases be non-magnetic, and it is desirable that the eddy-current loss be as low as possible. The nickel-iron alloys (either 18 per cent nickel—6 per cent manganese steel or high-nickel-manganese cast iron)

have an advantage over other non-magnetic materials in that the high electrical resistance exhibited reduces the eddy-current loss very materially. Hadfield's (12–14 per cent) manganese steel had a limited use, but suffered by not being forgeable or machinable.

### Nickel-Chrome-Steel Castings vs. Manganese-Steel Castings

The difficulties of handling manganese steel have always been a distinct detriment to this otherwise excellent product. In spite of this, manganese steel is very widely employed for wear-resisting castings, such as crusher and grinder parts and railroad trackwork. For the latter work it is further handicapped because manganese steel will flow under impact and because it is not weldable. Recently, therefore, a new development has arisen of replacing manganese steel for trackwork with a heat-treated nickel-chrome-steel casting. These nickel-chrome frogs, switches, and crossings wear as long or longer than manganese steel; do not flow under impact; are cheaper; and finally, when they are worn to a degree that would necessitate scrapping manganese steel, they can be built up by welding. Such castings analyze carbon 0.45–0.55, chromium 0.60–0.80, nickel 2.50–3.00, are heat-treated by a double anneal (similar to locomotive frames), and develop an average of 67,000 lb. elastic limit, 107,000 lb. ultimate tensile strength, 17 per cent elongation, and 26 per cent reduction of area with a Brinell hardness of 219.

### Nickel in Cast Iron

Often a line of investigation will be dropped because of apparent lack of results and later be followed to a successful conclusion. Back in the nineties experiments were carried on with nickel in cast iron, but results seemed to indicate that nickel was deleterious to iron, so up to a year or so ago the only uses for nickel in cast iron were in a mixture for rolls that lay in such a carbon range that it could with equal propriety be called a cast iron or steel, and as the lesser constituent of Mayari pig iron, used to some extent by foundrymen.

Finally the effects of nickel on cast iron were investigated thoroughly by laboratory methods, and it was found that the apparently bad results obtained with nickel were due to the complex nature of cast iron and the failure to recognize the effect of other elements when nickel was added.

Since these investigations the use of nickel cast iron has literally grown by leaps and bounds, and it shows promise of continued expansion.

Briefly, nickel in cast iron tends to refine the grain; to increase the machinable hardness; to increase the resistance to wear; to increase the strength; to reduce the chill; and to eliminate porosity. This list sounds like the collection of ills cured by some patent medicine, especially as some of them seem contradictory. This can be explained by saying that when nickel is to be added to cast iron the other elements must also be controlled in order to gain the desired end. Small additions—0.10 to 1.00 per cent—refine the grain of cast iron. Higher amounts—3.00 to 5.00 per cent—may coarsen the grain if the silicon is not controlled. Nickel is like silicon in that it assists in graphite formation and carbide decomposition, but there is a limit—roughly 3.00 per cent—beyond which silicon is detrimental to the iron. This is not true of nickel. Either silicon or nickel will tend to reduce chilling, but the addition of nickel causes no deterioration or loss of strength or increase in grain size.

Nickel improves the machinability of cast iron because it insures freedom from chilled areas and from hard carbide spots. By its use cast iron of 250 Brinell is as readily machined as ordinary iron at 200 Brinell. The hardening due to nickel is caused by an actual hardening of the iron matrix and not through action to increase the carbides in the iron.

The increase in the wear of castings when nickel is used is due first to this increased hardness, and secondly to the finer structure and freedom from carbide particles. Under wear conditions these hard carbide particles act as a lapping compound and increase the wear considerably.

These valuable characteristics are exhibited by the addition of nickel alone in cast iron, but other metals can be used to supplement the nickel, the most common one being chromium. The conjunction of the two is mutually advantageous. Chromium is a powerful hardener of iron, but is also very active in producing chills and carbide spots. This tendency is counteracted by nickel. The best ratio of nickel to chromium is two or three to one.

Cast iron with nickel alone or in combination with other elements is now used for a wide variety of purposes, such as automobile cylinders and pistons, differential spiders, Diesel-engine cylinders, hydraulic-press castings, valve and pipe-fitting castings, electrical-resistance grids, pipe balls, steam-cylinder bushings and piston rings, and rolls for steel-mill service.

Let us return to our starting point—alloy steel—for a moment. Roller and ball bearings are being applied more and more to heavy power machinery and to railroad equipment. The advantages gained in power saving, long life, and reliability are in many cases astonishing, and some clear-sighted people predict the practical replacement eventually of all metal bearings with these anti-friction bearings. This may be visionary.

Formerly practically all roller and ball bearings used for both races and rollers (or balls) a high-chrome steel. Now the majority of roller bearings are made of a nickel-molybdenum composition. The change was made because equally as good (or better) results can be obtained in service with the new steel, the necessary heat treatment is much simplified, and the alloys in the scrap are both recoverable. The last constitutes in itself a great saving. Only about 15 per cent of the steel made leaves the factory in the form of bearings; the other 85 per cent is returned as crop-ends or machining waste to be remelted.

Developments are constantly being made in nickel steels or nickel-iron alloys, new uses are created by new needs of industry, and the possibilities of this system, embodying as it does unusual and often contradictory characteristics, are far from exhausted. The most unexpected applications arise. For example, a certain combination of nickel and chromium with iron has a very low heat conductivity. It is now used abroad for handles on cooking utensils.

# The Manufacture of Seamless Tubes

By R. C. Stiefel[1] and George A. Pugh,[2] Youngstown, Ohio

*Two methods are today available in the manufacture of seamless tubes of 4 in. and greater diameter. These are the pilger process and the automatic or plug-mill process. The cost of installation is about the same for either process. The cost of tool equipment is much greater for the pilger process and it is claimed that the quality of the tube, particularly in the matter of service, is more uniformly reliable with the plug rolling process than with the pilger process.*

*Referring particularly to the plug rolling process the authors discuss the difficulties of operation and modern improvements aimed at obviating these difficulties. A distinction is emphasized between the part of the billet directly affected, or as the authors style it, "explored," by the mandrel, and the part which is unexplored, and the smaller the unexplored section is in relation to the full section of the solid billet, the fewer are the defects on the inside of the pierced tube. This leads to the conclusion that for the production of a given size tube, as small a solid billet as possible should be used. This is proved by a formula given for power consumption in piercing. The design of piercing mills is next considered from the same point of view and the most recent developments in the use of expanding mills are described.*

THE manufacture of seamless tubes is a branch of the steel business which lately has assumed enough importance to merit closer consideration than is possible in the little time available to the authors for this purpose. The following treatment of this subject is, therefore, based on the assumption that the reader is to some extent familiar with it, and the object is to deal only with the main difficulties encountered and with the possibility of eliminating them.

## Methods of Manufacture

The two chief methods of manufacture, besides a number of others of lesser importance, when considering the production of tubes, say, 4 inches and larger, are the pilger process and the so-called automatic-mill process. A general knowledge of both processes is assumed to be possessed by the reader.

The pilger process is in use chiefly in Europe and the automatic or plug-mill process chiefly in the United States. Experience with both processes has established the following comparable economic features between the two methods:

1 The output in tons with the plug-mill process is two or three times more than with the pilger process.

2 The cost of installation is about the same for either process or is rather less for the plug-mill process.

3 The cost of tool equipment, such as rolls and mandrels, is several times greater with the pilger process than with the plug-mill process.

4 Rolls and mandrels must be of the best grade of alloy steel in the pilger process, and in the plug-mill process they are of similar composition to those used in other steel working methods.

5 Maintenance of plant and tool equipment is much less costly and more simple with the plug-rolling method than with the pilger method.

6 The quality of the tube produced with reference to evenness of wall thickness and smoothness of outside and inside surface is better and more uniformly reliable with the plug-rolling process than with the pilger process.

7 Tube lengths obtained with the pilger-process are currently 40 ft. to 60 ft., and exceptionally up to 80 ft. or 90 ft. With the plug-rolling process, lengths obtained today are 30 ft. to 40 ft; with slight modification of the heretofore usual equipment, it will be possible to produce 50-ft. lengths.

8 The largest tubes produced with the pilger method are 20 in. in diameter and with the plug-mill process about 14 in. diameter. A recent development (expanding) will permit the production of 24 in. diameter and larger with the plug-rolling method.

The belief obtains, to a varying degree in the steel industry, that a better-grade steel (sounder steel) is necessary with the plug-rolling method than with the pilger method. This belief, or contention, is based on the assumption that for the plug-mill operation the billet is pierced to a wall thickness much less than is necessary for the pilger operation. This is an erroneous assump-

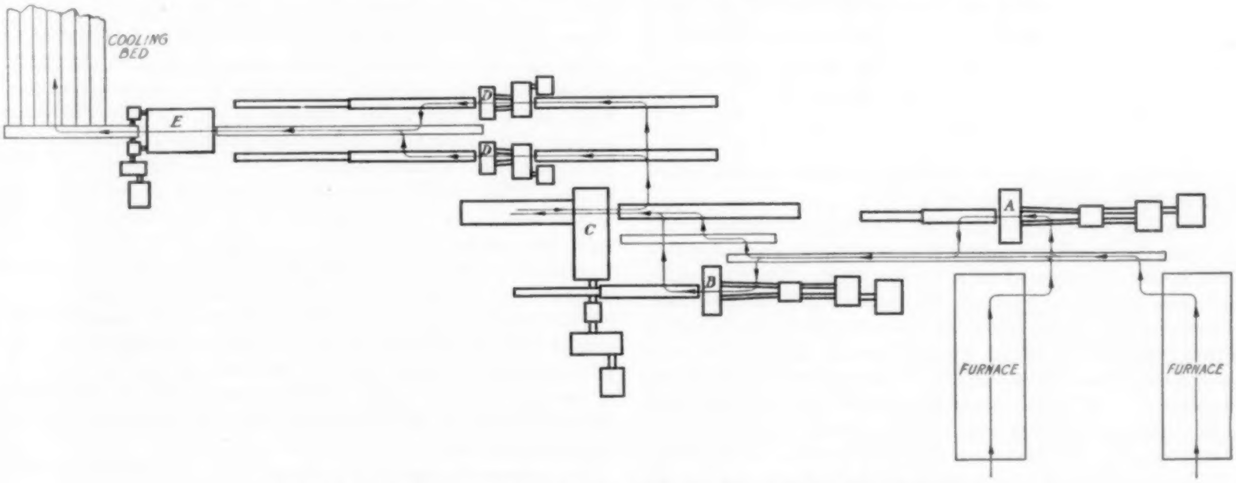


Fig. 1 Diagrammatic Layout of a Seamless-Tube Plug-Mill Unit

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tion where tubes of large size are concerned, as in this case the billet is pierced to a wall thickness substantially the same for the plug-mill operation as for the pilger operation.

The contention that better steel is required in the plug-rolling method is partly correct if applied only to the production of smaller sizes of tubes where the billet is pierced to a considerably thinner wall for the plug-mill method than for the pilger method. But in the production of these smaller tubes, a comparatively small-size solid billet can be used in the plug-rolling method, and with the use of small-size solid billets, which have had a large degree of refinement from the ingot down, the difficulties attributable to unsound steel have today practically been eliminated, at least in this country.

### Modern Plug-Mill Unit

The following description and accompanying illustration of a

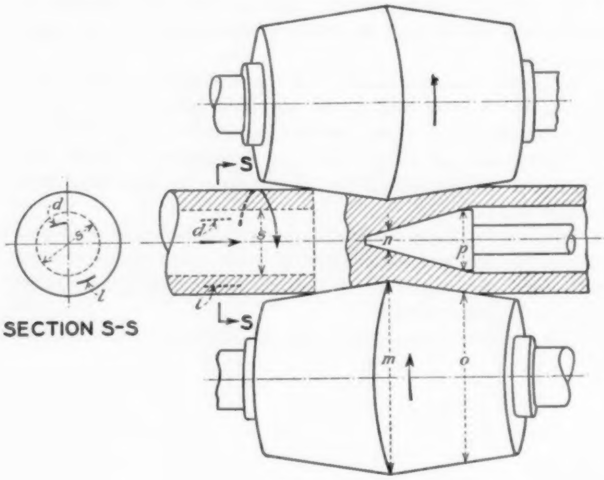


Fig. 2

typical modern plug-mill unit may serve toward a better understanding of the subject. (See Fig. 1.)

Steel billets are charged into the piercing-mill furnaces, and from there into piercing machine *A* or piercing machine *B*, either of which can be operated as a piercer, or the first piercer for piercing only and the second piercer for enlarging the pierced billet.

From either of the piercing machines the billet is conveyed to the plug mill *C*. Here the billet is passed through the rolls two or more times for the purpose of reducing wall thickness and elongating it. All of the movements of the billet are performed mechanically on the plug mill with practically no hand labor.

From the plug mill the tube is conveyed to either of the reeling machines *D*, in which it is acted upon by oblique rolls on the outside and a cylindrical mandrel on the inside, for the purpose of equalizing the wall thickness and smoothing its outside and inside surfaces. In the reeling operation the diameter of the tube is slightly increased, resulting from a slight reduction of the wall thickness.

After the reeling operation, the tube is passed through the sizing machine *E* for the purpose of reducing it to the required diameter. This machine usually contains several pairs of grooved rolls. The tube, after leaving the sizing machine, is shifted onto a conventional type of cooling table consisting of a number of slowly moving conveying chains, rolling the tubes on a slightly inclined table.

### Difficulties With Steel

It is a fact that in the manufacture of seamless tubes, the quality (soundness) of the solid billet is of great importance; and herein lies one of the chief difficulties encountered in this manufacture, whether it be by the pilger process or by the plug-mill process.

Defects may result on the inside of the tube from segregation or blow holes at or near the center of the solid billet, and on the outside of the tube from defective bar-mill practice, or from defects (tears, slivers, and blow holes) at or near the surface of the solid billets.

The defects on the outside of the tube, resulting from faulty bar-mill practice and from tears and slivers on the surface of the solid billet, can be and have been traced to the source, and much improvement has been made in this respect.

### Elimination of Steel Defects

The elimination or reduction in number of defects on the inside and outside of the tube resulting from segregation and blow holes can also be greatly helped, as will be evident from the following:

Inside and outside surface defects attributable to segregation can hardly be eliminated altogether, but such defects can be greatly reduced in magnitude by giving the ingot more rolling, reducing it to a smaller-size round billet than has been customary heretofore for the production of a given size tube.

Inside surface defects attributable to blow holes can be largely reduced in number or entirely eliminated.

Referring to Fig. 2, it will be understood that the piercing mandrel over which the billet is forced explores, so to say, the inside of the solid billet on its full length for defects. An annular outside volume of the solid billet, represented in dotted lines, equal to the volume of the pierced billet, has remained unexplored by the mandrel. Any defect *d* in the explored section *S* of the solid billet, in the shape of what is commonly called a lamination, resulting from a blow hole in the ingot from which the billet was rolled, is laid out or exposed on the inside surface of the pierced billet in the shape of a tear, seam, or lap, while any such lamination *l* existing in the unexplored annular section of the solid billet will remain practically undisturbed in about the same relative location in the annular section of the pierced billet. (Therefore, the smaller the explored section *S* is in relation to the full section of the solid billet, the fewer such laminations may be contained in the displaced central volume of the billet and consequently fewer or no tears, seams, or laps may be obtained on the inside of the pierced billet.)

This condition again points in the direction of using as small a solid billet as possible for the production of a given size tube. It will readily be seen that the explored or central section *S* of the steel billet is rapidly reduced in relation to the full section as the diameter of the billet is reduced, the unexplored section remaining the same.

The logical conclusion to be drawn from the foregoing is that by using a billet larger in diameter than necessary an unusual number of inside defects may result.

The described condition with reference to location of laminations that may or may not result in defects on the outside or inside of the tube should serve as an indication to the steel maker as to where the blow holes should be located in the ingot if they cannot be entirely eliminated. In other words, with reference to Fig. 3, if the inner section *A*, in relation to the full section of the ingot, is the same as the explored section *S* of the solid billet in relation to the full section of the solid billet, Fig. 2, then the blow holes should be located as centrally as possible in the sectional outer area *B* of the ingot in order not to result in injurious outer or inner surface defects in the tube.

A closer cooperation in this respect between the tube-mill operator and the steel maker should result in better conditions as to surface defects in the tube.

With reference to the occurring surface defects on the tube, it is well known that the piercing operation is a test of the steel; piercing means penetrating the center of the billet, spreading the displaced metal of the center toward the outside, at the same time elongating the billet. The spreading and stretching stresses set up in the billet by the piercing operation are hard

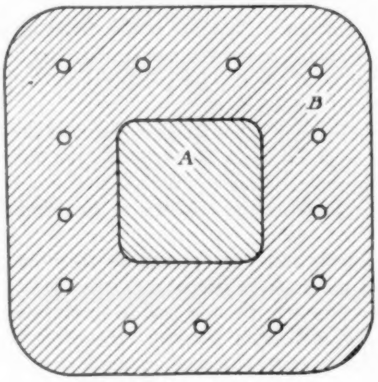


Fig. 3

on the steel and tend to aggravate existing defects in the billet. These stresses, and resulting aggravations of existing defects, are increased in the piercing operation proportionately with a decrease of the wall thickness and an increase of the elongation; and they are decreased proportionately with an increase of wall thickness and a decrease of elongation. Hence, the conclusion is reached that a given size tube should be produced by using as small a billet as possible in order to set up a minimum of stresses and corresponding minimum punishment of the steel.

### Power Consumption

Another way to prove the correctness of this statement is as follows. It is clear that the more power that is used to pierce a billet of a given size in a given time, the more punishment is given to the steel. Now, the power absorbed is represented by the formula: Kilowatt-seconds $= C \times$ weight of billet in lb. $\times$

$$\log\left(\frac{\text{length of pierced billet in feet}}{\text{length of solid billet in feet}}\right)$$

From this formula, in which $C$ represents a constant value, it is evident that the power can be reduced to a minimum by increasing the length of the solid billet and decreasing its diameter correspondingly, maintaining the same weight. All of which results in the fact that by using smaller billets not only is the steel punished to a lesser degree but a considerable saving in power also is obtained.

### Design of Piercing Pass

Until lately there has been no good and reliable procedure established to determine the most favorable size of solid billet from which to produce a given size tube; it has been largely a matter of "rule of thumb." A common practice was to choose a solid billet of a diameter approximately the same, or somewhat smaller, than the desired tube. The correct method to determine the most favorable size of solid billet is as follows.

The piercing diagram illustrated in Fig. 4 is arranged in such a manner that the converging pass $CA$ formed between the rolls establishes enough grip on the billet, by the time the latter has progressed to point $D$, to force it over the point of the mandrel. The elongation of the billet, that is, the reduction of its cross-sectional area, should be done only in the converging pass from $C$ to $A$ with a minimum draft or reduction of the billet. The diverging pass, from $A$ to $B$, between the rolls and the mandrel is arranged so that the cross-sectional area of the billet at $A$ is equal to that at $B$. In a piercing pass established to fill these conditions, the billet is only subjected to expansion in the diverging pass and to elongation in the converging pass.

It will be clear from a closer study of Fig. 4 that the metal of the billet has a fair chance to flow lengthwise (or the billet has a chance to elongate) in the converging pass where it is gripped between the two roll faces forming a comparatively large included angle $a$ between them. But where the metal is gripped between the two diverging roll faces and the two corresponding mandrel faces, it becomes almost impossible for it to flow lengthwise between the respective roll and mandrel faces which form a smaller flow angle $g$ for the metal than is the case in the converging pass. On the other hand, it is evident from the cross-section at $yy$ of Fig. 4 that the flow angle in the transverse direction is greater than in the longitudinal direction, from which it follows that in the diverging pass the metal meets less resistance to flow in the transverse direction (expansion) than in the longitudinal direction (elongation). From this analysis it becomes clear that the diverging pass should logically be determined, as described, so as to compel expansion, and no elongation of the billet, instead of by using a mandrel the shape of which is determined by guess work.

The foregoing procedure of determining the piercing conditions for a given size tube is a sure way to obtain the best results, with reference to punishment of the steel and consumption of power. It constitutes the subject of a pending patent application.

### Conflicting Factors Confronting Management

Since the piercing operation, even if performed under the most favorable conditions, is a very severe test of the steel, it is of

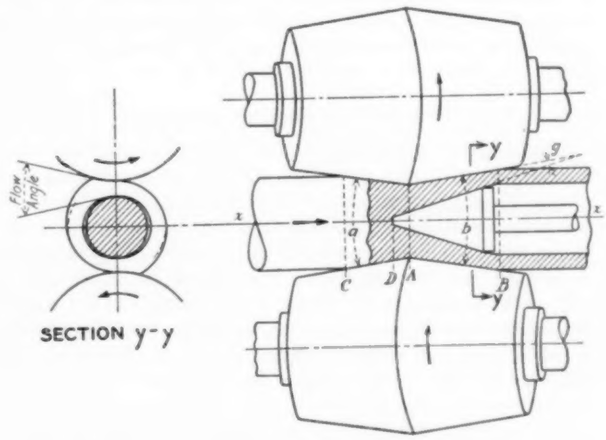


Fig. 4

the greatest importance to make sure that this operation is being performed under conditions as favorable as possible. When it happens that losses occur, that is to say, when defective tubing is produced, a chaotic condition usually arises. The operating management of the tube mill, believing that working conditions have been maintained constant and proper, attributes the loss exclusively to defective metal, whereas the steel maker, believing that the metal is not defective, attributes the losses exclusively to improper conditions in the piercing procedure, a case of "the pot calling the kettle black," and the general management is at a loss where to place the blame. Manifestly it is desirable to eliminate one of the two causes of defective tubing so that

there obtains no more uncertainty as to where to look for the remedy. This can be done by adopting the design of the piercing pass in the manner explained in the preceding paragraph, by eliminating the "rule of thumb" practice.

In the foregoing procedure of determining the most favorable piercing conditions it was assumed that the angles $a$ and $b$ of the converging and diverging passes were given as well as the type of roll, namely, barrel-shaped rolls with their axes practically parallel to the pass line $xx$, a type of roll which has commonly been used in the production of the larger size tubes, say about 5 in. diameter and larger. These angles and the type of roll constitute the elements which determine more or less favorable working conditions and the choosing of them should be given careful consideration.

### Function of Piercing Rolls

It will be noted from Fig. 4 that at the first contact $C$ established between the billet and the rolls, the diameter of the roll is small while the billet is large; as the billet progresses from $C$ to $A$, the diameter or circumference of the billet decreases while that of the roll increases; from $A$ to $B$ the reverse takes place, that is, the diameter or circumference of the billet increases while the corresponding diameter or circumference of the rolls decreases. This irrational relation between corresponding diameters, and consequently speeds, of the rolls and billets at different contact points during the progress of the billet through the piercing pass, results in the setting up of the injurious stresses in the billet heretofore referred to; it also results in the breaking up of the center of the billet before it reaches the point of the mandrel, thereby favoring the penetration of the mandrel into the center of the billet; but it also has the effect of producing enormous friction or slippage between the rolls and the billet on the outside as well as between the mandrel and the billet on the inside. When considering that the metal pressure exerted by the rolls on to the billet may amount to several hundred-thousand pounds, it will be evident at once that much slippage under such great pressure will result in enormous waste of power.

### Function of Piercing Mandrel

The peculiar functioning of the mandrel in the pass of the now customary piercing machine also greatly contributes to the setting up of injurious stresses in the billet. Referring to Fig. 2, it is apparent that the rolls, being obliquely disposed in relation to the axis of the billet or pass, tend to rotate the billet and feed it forward over the mandrel. The axis of the billet and the axis of the mandrel being the same, it is clear that the mandrel has no forward feeding effect on the billet; the billet therefore is fed or pulled or pushed forward on the outside by the rolls while the mandrel on the inside tends to prevent it from moving forward.

Furthermore, it will be noted that to the large diameter $m$ (Fig. 2) of the roll is opposed the small diameter $n$ of the mandrel, while to the small diameter $o$ of the roll is opposed the large diameter $p$ of the mandrel. The torsion and slippage stresses to which the outside of the billet is subject by the speed differences of the rolls, as explained before, are therefore being repeated for the same reasons on the inside by speed differences of the mandrel. All this occurs under the heavy pressure on the metal necessary to displace it from under the contacting surfaces between it and the rolls and mandrel.

What has been stated heretofore with reference to power absorption by slippage or friction by the rolls on the outside of the billet, also applies in connection with the similar great friction or slippage occurring between the mandrel and the inside of the billet.

### Piercing Power

The total power necessary in piercing consists of three main divisions:

1 Power absorbed by machine friction
2 Power absorbed by roll and mandrel friction on the metal
3 Power absorbed by metal displacement.

A careful analysis of the three power divisions would probably prove that, in many cases, the power absorbed by roll and mandrel friction on the metal is far greater than the power absorbed by actual metal displacement.

From the foregoing it becomes evident that the power required in piercing is of injurious character to the steel and that the amount of power required to produce a tube of a given size in a given time represents the measure of punishment imparted to the billet.

The tendency, therefore, should be to reduce the power in piercing to a minimum in the manner described and rather spend a little more power in the bar mill to produce billets of smaller diameter, the additional bar-mill power required being of a beneficial character to the steel, refining it to a higher degree. Thus a threefold advantage will be obtained; better steel, less power consumption, and less punishment of the steel in piercing.

It is possible to improve the conditions obtaining with reference to the occurring torsional and slippage or friction stresses on the outside and inside of the billet with piercing mills of a different type than that which is now customary.

Referring again to Fig. 4, it is possible, for instance, in many applications, to use piercing rolls of different type than those indicated, whereby most of the metal friction in the diverging pass $AB$, the most injurious, can be eliminated. Some headway has been made in this direction and it is probable that much more progress can be made from now on when new capital to be invested in seamless-tube-mill installations may become less hesitant to lend itself to a justified departure from the trodden path.

There are many other interesting and important features in connection with piercing in particular, as well as with plug rolling and reeling, that deserve more study and understanding by those engaged in this manufacture in order to make intelligent decisions when difficulties arise, particularly in case of difficulties with steel. On account of lack of time, it is impossible to undertake at present a complete detailed study of all features; therefore, this article touches only on the most important ones.

The foregoing deals exclusively with the difficulties encountered at times with steel. However, the conclusion should not be drawn that these difficulties are constant and standing in the way of producing seamless tubes as cheap or cheaper than lap-welded tubes. Good yields, varying between 80 per cent and 90 per cent from solid billet to finished tube, are now being obtained when producing lengths of about 30 ft. to 35 ft., which is a creditable result when considering crop-end losses and about 3 per cent furnace loss.

### Expanding

Another inconvenience inherent in the now usual seamless plants lies in the fact that when it is necessary to change production from one size of tube to another, considerable time, five hours or more, is lost in making the necessary shift in the machine equipment and size of solid billet.

Great advantages can be obtained in this respect by replacing the now commonly used reeling machine with an expanding machine which may function the same as the present reeling machine or may be used to expand the tubular body coming from the plug mill, or from the piercing machine, into larger

sizes of correspondingly thinner walls. Sufficient experimental work has been done to justify the assumption that this expanding method will permit the production of large size tubes up to about 24 in. diameter at comparatively little additional power requirement and with an initial plant cost equal to the cost of a plant for the direct production of tubes with the now usual plug-mill process up to about 14 in. diameter. Allowance for additional cost of larger finishing equipment will, of course, have to be made.

The benefits obtained from the expanding mill will become evident by a study of Fig. 5. A tubular body of 14 in. diameter and wall thickness *d*, coming from the plug mill or from the piercing mill, is expanded to 24 in. diameter of corresponding wall thickness *e*. If a tube of less than 24 in. diameter should be required, for instance, of a diameter as shown by dotted line, it

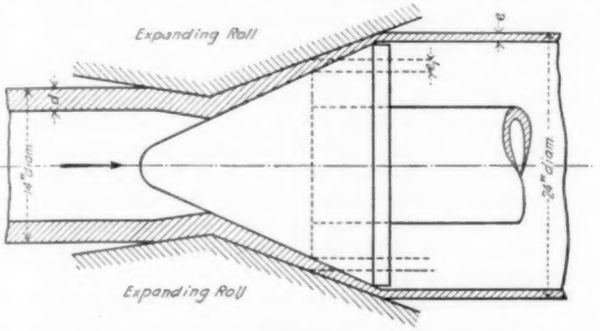


Fig. 5

could be produced without changing the setting of the rolls of the expanding mills by simply using a smaller expanding mandrel, as shown by dotted lines. This smaller tube, however, would have a wall thickness $e_1$, in the same proportion greater than $e$ as its diameter is less than 24 in. Should the wall thickness of the smaller tube have to be less than $e_1$, then it could be obtained by simply preparing a tubular body at the plug mill or piercing mill of the same diameter (14 in.), but of correspondingly less wall thickness than $d$. On the other hand, if the wall thickness $e_1$ should be required to be greater than shown, then the wall of the entering tube would have to be correspondingly greater than that shown and designated by $d$.

It will be seen, therefore, that with the roll setting shown, tubes of varying diameter and wall thickness can be obtained at the expanding mill from a tubular body of constant diameter of 14 in. but of different wall thickness.

The same advantages with reference to simplification in the production of different sizes which are described in the foregoing grouping of sizes from 14 in. to 24 in. obtain when grouping other sizes as, for instance, all sizes from 8-in. to 14-in. diameter and all sizes from 5-in. to 8-in. diameter.

It must be noted here that the indicated division of all sizes of tubes from 5 in. to 24 in. in diameter into only three groups, each to be produced from only three different tubular bodies of constant diameters, was given as an illustration only, and that it will be advisable to arrange the working program for more than only three groups in order to obtain the best possible piercing condition for one size of tube of each group and not too much deviation from the best piercing conditions for all the other sizes of each group.

This great flexibility in sizes obtainable from an entering tube of constant diameter dispenses with changes of guide and roll settings at the plug mill and at the piercing mill. The variation required in the wall thickness $d$ of the entering tubular body can be obtained at the plug mill and piercing mill by a simple change of mandrels. At the expanding mill a change in the setting of the outlet guides would be required to accommodate the varying diameters from 14 in. to 24 in. of the outgoing tubes, but no change of the inlet guides would be required, the entering tube being of constant diameter. Changes in the settings of the reeling machine and sizing machine would have to be made in the same way as in the present installations.

Referring to Fig. 6, a modification of Fig. 5, the expanding mandrel is provided with two different cones *A* and *B*, cone *A* forms a converging pass for the entering tube wall between it and the expanding rolls, and cone *B* forms a parallel pass for the tube wall between it and the expanding rolls. On cone *A*, the entering tubular body has its wall reduced and its diameter enlarged, and on cone *B* the wall is smoothed out in exactly the same manner as is now the case in the customary reeling machine. By the use of this modified mandrel, the expanding and reeling operations may be performed simultaneously in the thus-formed expanding-reeling pass.

The expanding method referred to forms the subject of U. S. Patents.

In the now customary plug-mill installations, the practice is frequently to change the size of solid billet when producing tubes of different diameters. With the use of the expanding mill, the requirement of billets of many different sizes would disappear, only a few standard sizes of billets becoming necessary.

The advantages resulting from such a standardization in the working of steel in the hot state needs no comment.

The benefits obtainable with the expanding mill apply equally well to pilger-mill installations. In fact, these benefits will be more pronounced in a pilger-mill plant than in a plug-mill plant, for the reason that a standardization to fewer sizes of the much more expensive equipment in rolls and mandrels, necessary for a pilger-mill plant, will result in far greater economy than in a plug-mill plant. These benefits can be summarized as follows:

1 The expanding mill can be used for the same purpose as the now commonly used type of reeling mill, or it can be used to reduce the wall thickness and increase the diameter of the tube; or it can be used to accomplish both—expanding and reeling simultaneously.

2 Comparatively little power is required, for the reason that the character of impingement on the steel by the expanding

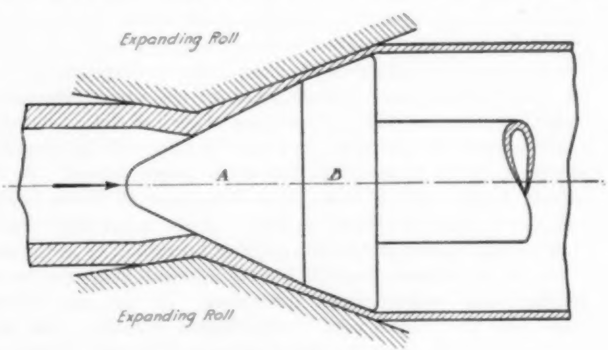


Fig. 6

rolls is much more favorable with reference to "flow of metal" than is the case if, in the absence of the expanding mill, the same reduction of wall thickness would have to be made at the plug mill or pilger mill.

3 A thicker wall can be produced at the plug-mill or pilger-mill operation.

4 A thicker wall can be produced at the piercing operation; hence, less punishment of the steel and less aggravation of existing defects in the billets.

5 On account of being able to produce thicker walls at the piercing-mill and plug-mill or pilger-mill operations, these operations become easier and, as a result, should favor more output.

6 Time is saved when changing from one size to another.

7 Fewer sizes of solid billets are required.

8 The equipment required for the production of the tubular body at the piercing mill and plug mill or pilger mill becomes standardized to few sizes (diameters).

9 The expanding mill can be added to any kind of existing installation suitable to produce hollow blanks, thus enabling the production of larger tubes with existing equipment at comparatively little cost.

### Output, Cost, and Quality

The output in a modern plug-mill plant in tubes of 5 in. diameter and larger is about 200,000 tons per year.

The cost of production of seamless tubes of usual sizes is the same as, or less than, that of lap-welded tubes. Inasmuch as the seamless-tube industry is comparatively new, it is reasonable to assume that more progress will be made with reference to cost of production.

The method of manufacturing seamless tubes permits the use of high carbon steel or alloy steel, resulting in a product of superior quality, with reference to strength and usage. It is also applicable to other metals such as copper, brass, aluminum, etc., all of which are impossible by the welding process.

## Discussion

H. H. Murray.[3] This is a very interesting general account of the process of the manufacture of seamless tubes in what might be referred to as the larger sizes. There are, however, several points which give ground for further discussion.

Taking first the question of the relative merits of the pilger and plug-mill processes—while the writer is a firm believer in the superiority of the plug-mill process, it is well sometimes for us to analyze our views lest they be tainted with prejudice—the pilger process is, and has been for a number of years, very largely used in Europe, whereas the automatic or plug-mill process has made little progress except in the United States. While the Europeans in our opinions may be somewhat backward in some directions, there must be some good reason for their preference for the pilger method of manufacturing seamless tubes. There are two installations of pilger mills for large-size pipe in the United States, and it might be of interest to get expressions from those familiar with the operation of each of these two mills. The statement is made that the output in tons with the plug-mill process is two or three times that of the pilger process. In the output of every mill there is a controlling factor or "bottle neck," and in the plug mill shown in Fig. 1 of the paper this "bottle neck" would apparently be the piercing operation, or in the case of the use of piercers $A$ and $B$, piercer $B$, which performs the expanding and wall-reduction operations. In the case of the pilger mill the "bottle neck" is the rolling operation, but as a general rule more than one pilger rolling mill is used in conjunction with one piercing mill. The statement is made that the cost of installation is about the same for either process; but considering that the pilger mill generally consists of a piercer and one or more sets of pilger rolls, and sometimes reeling machines, it is believed that such an installation should not cost any more but would probably cost less than a layout with two piercing mills as shown in Fig. 1. Regarding the cost of tool equipment, rolls, mandrels, and maintenance, there is nothing to say, as it is generally conceded that in the case of the pilger mill this cost is higher than in the case of the automatic mill. Regarding the quality of the tube, while as a whole plug-mill tubes are of better quality than tubes from the pilger mill, in certain details a pilger-mill tube is superior. One of the great troubles of the plug-mill operator is the elimination of internal scratches. The pilger mill overcomes this difficulty, making a tube with a very fine inside surface, but the outside surface of such tubes does not compare with a tube made on a plug rolling mill. The writer would like some reliable information as to actual tonnage output on a modern pilger mill where two rolling mills used in conjunction with the piercer are making long tubes of a size and length to give maximum output.

Regarding the question of steel quality, the defects which give the seamless-tube manufacturer trouble exist in the billet, of course, and are exposed as stated by the authors in the piercing operation. In the case of the pilger mill the tubes are pierced with a very heavy wall and are reduced to the required thickness in the pilgering process, which is almost equivalent to a forging operation, and this tends to close up and conceal many defects. In the installation referred to by the authors the general idea would be to pierce a wall of the same thickness as would be pierced on the pilger mill and to reduce this wall thickness in a subsequent piercing machine designed for expanding and wall-reducing operations. Whether this would hide these defects to the same extent as the other operation, however, the writer is not prepared to say.

The authors state that the difficulties experienced in seamless-tube manufacture should not lead us to draw the conclusion that seamless tubes cannot be produced as cheaply as or cheaper than lap-welded tubes. All of us who manufacture seamless tubes are looking forward to the time when this will be accomplished, but at the moment, excepting in perhaps a few individual cases, this has not been generally accomplished. Most of the seamless-tube mills in existence were designed to take care of a more or less general business of varying sizes and types of tubes, whereas lap-weld mills as a rule, due largely to the enormous requirements of the oil industry, are built to give a maximum output on a narrow margin of sizes processed in large quantities. When the hesitancy of capital referred to by the authors has been overcome, perhaps we may have seamless mills built along these latter lines; and when that time comes we should be well able to meet the lap-weld man on his own ground. In this connection, of course, we should not lose sight of the fact that at the present time raw material of a quality suitable for making seamless tubes is more expensive than skelp for lap-welded tubes. The very fact that seamless tubes require a superior grade of material for their successful manufacture, as compared with the material which may be used for lap-welded tubes, although disadvantageous from a cost point of view, is of considerable advantage to the consumer in the matter of intrinsic quality.

J. B. Wharton.[4] Reference is made in this paper to the quality of steel required to produce seamless tubes by the pilger and automatic-mill processes. It was stated that for the tubes of larger diameter, say above 6 in., the quality of steel required is the same. A brief description of the two processes may be helpful in determining whether this is the case.

For the pilger process, cast round ingots, always considerably larger than the finished tube, are used. These ingots are reheated and pierced. The inside diameter of the pierced blank is approximately the same as will be the inside diameter of the finished tube; the outside diameter, however, is 3 to 4 in. larger than will be that of the finished tube. The pierced blank is

[3] Superintendent, Babcock & Wilcox Tube Co., Beaver Falls, Pa. Mem. A.S.M.E.

[4] Chief Engineer, Standard Seamless Tube Co., Ambridge, Pa.

then forged down in the pilger mill to the desired outside diameter. This operation tends to forge out and cover up any defects developed in the piercing operation.

For the automatic-mill process, rolled rounds are used. The diameter of the round is much smaller than the finished tube. The initial piercing leaves a heavy wall comparable to the pierced blank for the pilger mill. The diameter of the pierced blank is still much smaller than the finished tube.

In the second piercing operation the blank is expanded 30 to 40 per cent in diameter, is elongated 50 to 100 per cent, and the wall is reduced to a thickness of about 50 per cent greater than that of the finished tube. The second piercing operation therefore not only aggravates any defects developed in the first, but uncovers others which may have been in the steel and not brought out in the first piercing.

As opposed to a reduction in diameter in the pilger process, there is an expansion in diameter in the automatic-mill process. It would therefore seem clear that a better quality of steel is required for the automatic process than for the pilger.

The writer understands that the power formula, kilowatt-seconds $= C \times$ weight of billet $\times \log \dfrac{\text{length of pierced billet in feet}}{\text{length of solid billet in feet}}$, was developed before heavy-wall piercing became general practice and has not been thoroughly tested for heavy-wall piercing. The writer has made a few experiments along this line and has been unable to obtain reasonable results.

By taking power charts on piercing various sizes of tubes and solving the formula for $C$ we ought to get a reasonable relation between the various values of $C$. The results of such a calculation follow:

$8^5/_8$-in. $\times$ 32-lb. casing, $C = 97.4$
$9^5/_8$-in. $\times$ 36-lb. casing, $C = 126.2$
$11^3/_4$-in. $\times$ 60-lb. casing $C = 83$
$13^3/_8$-in. $\times$ 61-lb. casing $C = 305$

However, very consistent results on the power required to expand a pierced billet have been obtained. The method used was the determination of the power required to displace a given volume of metal per second. The results and method of procedure are shown in Table 1 and Fig. 7.

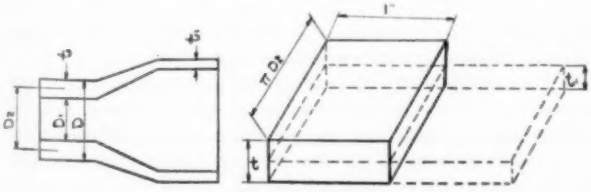


FIG. 7

$\left(\frac{\pi D^2}{4} - \frac{\pi D_1^2}{4}\right) - \pi D_2 t_1$ = volume of metal displaced per unit of feed of billet, or when all dimensions are expressed in inches and time in seconds the results will be kilowatts per cubic inch of metal displaced per second.

By referring to Table 1 we find that the kilowatt per cubic inch of metal displaced per second varies from 11.5 to 14.2. This result is reasonably close when we consider the fact that no attempt was made at temperature control other than the furnaceman's judgment.

The disk type expanding mill has, the writer believes, been used successfully in this country as a reeler by one pipe manufacturer. Its theoretical action is, however, more nearly correct for an expanding operation than for a reeling operation. By referring to Fig. 8 it will be seen that the speed of the disk at diameter D at beginning of reeling cone is less than the speed of the disk at diameter D at end of reeling cone, while the diameter of the pipe remains practically constant. It can readily be seen that this condition produces a constant slip between disk and tube.

The following calculations show the method of arriving at the results given:

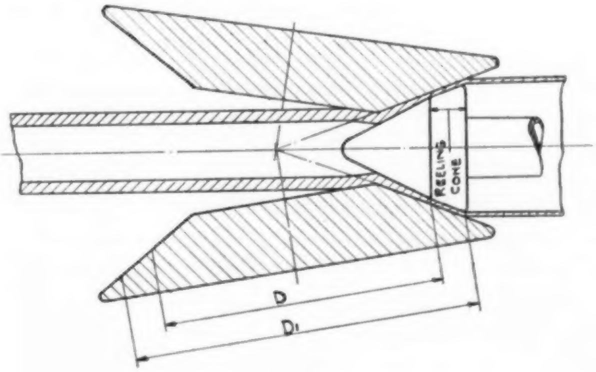


FIG. 8

$8^5/_8$ in. $\times$ 32-lb. casing
$L_1 = 8.3$
$L = 11.57$
$W = 935$
$S = 11.4$
$KW = 1150$

$$C = \frac{1150 \times 11.4}{935 \times \log 1.392} = \frac{1150 \times 11.4}{935 \times 0.1433} = 97.4$$

$9^5/_8$ in. $\times$ 36-lb. casing

$$KWS = C\ W \log \frac{(L)}{(L_1)}$$

$$C = \frac{KWS}{W \log \dfrac{(L)}{(L_1)}}$$

$KWS$ = kilowatt-seconds
$C$ = constant
$W$ = weight of steel in pounds
$L$ = length of pierced billet in feet
$L_1$ = length of solid billet in feet
$L_1$ = 8.1 ft.
$L$ = 10.4 ft.
$W$ = 1060
$S$ = 13.2 sec.
$KW$ = 1100

$$C = \frac{1100 \times 13.2}{1060 \times \log 1.282} = \frac{1100 \times 13.2}{1060 \times 0.10788} = 126.2$$

$11^3/_4$ in. $\times$ 60-lb. casing
$L = 13.4$
$L_1 = 8.0$
$W = 1712$
$S = 13.46$
$KW = 2400$

$$C = \frac{13.4 \times 2400}{1712 \times \log \dfrac{13.4}{8}} = \frac{13.4 \times 2400}{1712 \times \log 1.67} = \frac{13.4 \times 2400}{1712 \times 0.2227} = 83$$

$13^3/_8$ in. $\times$ 61-lb. casing
$L = 8.6$

$L_1 = 7.58$
$W = 1825$
$KW = 2350$
$S = 12$

$$C = \frac{12 \times 2350}{1825 \times \log 1.135} = \frac{12 \times 2350}{1825 \times 0.0549} = 305$$

TABLE 1

| | Size of finished pipe | | | | |
|---|---|---|---|---|---|
| | 9 in. | 9 5/8 in. | 10 3/4 in. | 11 3/4 in. | 13 3/8 in. |
| Weight of pierced billet, lb. | 1345 | 1060 | ...... | 1712 | 1825 |
| O.D. pierced billet, in. | 7 1/4 | 7 1/2 | ...... | 9 | 10 1/2 |
| Wall pierced billet, in. | 1 1/2 | 1 5/8 | ...... | 1 5/8 | 2 1/2 |
| Area pierced billet, sq. in. | 27.1 | 29.99 | ...... | 37.65 | 62.84 |
| Mean diameter pierced billet, in. | 5 3/4 | 5 7/8 | ...... | 7 3/8 | 8 |
| Mean circumference pierced billet, in. | 18.06 | 18.45 | ...... | 23.17 | 25.13 |
| O.D. expanded billet, in. | 9 1/2 | 10 1/8 | ...... | 12 | 13 7/8 |
| Time required to expand, sec. | 14.4 | 16.8 | ...... | 17.3 | 12 3/8 |
| Wall expanded billet, in. | 11/16 | 11/16 | ...... | 7/8 | 3/4 |
| Mean circumference pierced billet times thickness expanded billet | 12.4 | 12.7 | ...... | 20.4 | 18.9 |
| Displaced metal per inch length pierced billet | 14.7 | 17.29 | ...... | 17.25 | 44.04 |
| Feeding speed, in. per sec. | 12.35 | 7.50 | ...... | 9.4 | 4.8 |
| Rate displacement, cu. in. per sec. | 182 | 130 | ...... | 162 | 212 |
| Total kilowatts | 2100 | 1850 | ...... | 2250 | 2600 |
| Kw. per cu. in. displacement, per sec. | 11.5 | 14.2 | ...... | 13.9 | 12.3 |
| Angularity of rolls, kw | 10 | 11 | ...... | 10 | 10 |

W. M. Selkirk.[5] Ever since the inception of seamless tubes we have heard that the industry is in its infancy. The last few years, however, have seen very rapid strides in the way of development of the art of manufacturing them.

As stated by Messrs. Stiefel and Pugh, the piercing operation is a very severe test of the quality of steel. This is especially true where light-walled hollow blanks, such as are required under the present operating conditions for the plug mill, are to be produced. Steel cast ingots pierced with heavy walls have been used in Germany in connection with the plug mill, but this practice involves as many as 18 passes in the mill, also reheating and sawing of the rolled billets between certain passes in order to produce a hot-finished tube of commercial size and quality for general use, a procedure which would not be considered economical in this country.

I have been much interested in the authors' references to the expanding process. It is apparent that by means of this process a pierced blank with a much heavier wall would be necessary for the production of all classes of seamless tubes. This condition would be very much more favorable for the use of cast ingots for the plug mill, as well as for the pilger mill. It is also apparent that by this process, which renders possible the standardization of sizes of pierced and rolled tubes prior to the expanding, a great deal of equipment, especially that used in connection with the pilger process, could be eliminated. I am of the opinion that this method if put into practice would demonstrate a decided advancement in the manufacturing art.

A comparison has been made between the plug-mill process and the pilger-mill process. It might be interesting to know that while it is customary to produce a light-wall hollow blank for the plug mill, the pilger mill demands a billet with a heavy wall, rendering the use of cast ingots possible. It might also be of interest to know that tubes over 130 ft. in length have been produced on the pilger mill in this country.

While this displays a certain economy with regards to scrap loss, cropping, etc., the commercial value of tubes of such length is questionable, due principally to handling and transportation difficulties. It might be said that the length of tubes possible to roll by the pilger mill is limited only by the size of ingot it is practical to heat and pierce.

I have studied with a great deal of interest the paper submitted by Messrs. Stiefel and Pugh and wish to congratulate them on the very able and interesting way in which they have described the manufacture of seamless tubes.

[5] Chief Engineer, Seamless Tube Division, Pittsburgh Steel Co., Monessen, Pa. Mem. A.S.M.E.

W. R. Clark.[6] The writer's experience in piercing has been confined entirely to brass and copper. However, further light on one or two things with reference to the power requirements presented in this paper would be valuable. The first formula gives a kilowatt-second equal to $C$ times the weight of billet in pounds times the logarithm of the length of pierced billet in feet divided by the length of solid billet in feet. The writer's understanding is that this expression applies only to the power necessary to move the material in the billet itself, irrespective of any friction applied in the mill or friction applied by the rolls and the plug to the outside and inside surfaces of the tube being rolled.

We have noted that if a piercing point is introduced too far into the mill, the power requirement goes up materially, resulting from increased friction, caused by a slowing down of the feed of the billet, that friction being manifest in increased power per pound of billet rolled per minute.

W. Trinks.[7] The writer has noticed that in European mills for piercing billets, the angle of the roll is adjustable when looking at the plan view, whereas it is fixed when looking at the elevation. In American mills the reverse is true. There must be some reason. The writer would like an explanation from Messrs. Stiefel and Pugh as to the reasons for this.

Furthermore, a study of available literature shows that there is a difference in the angle of the conical rolls. In some rolls the entering angle is large and the leaving angle is small, whereas in other rolls the opposite is true. Again, is that something that just happens or is there a reason for it?

[6] General Works Manager, Bridgeport Brass Co., Bridgeport, Conn. Mem. A.S.M.E.

[7] Professor of Mechanical Engineering, Carnegie Institute of Technology, Pittsburgh, Pa. Mem. A.S.M.E.

# Mechanical Properties of Aluminum Casting Alloys at Elevated Temperatures

By R. L. TEMPLIN,[1] C. BRAGLIO,[2] and K. MARSH,[3] PITTSBURGH, PA.

*The investigational work described in Part I of the paper includes tensile results obtained from "short-time" high-temperature tests of ten different aluminum casting alloys and very pure cast aluminum, and for various heat treatments in the case of some of the alloys. All the specimens tested were sand cast and include the more common commercial casting alloys of aluminum.*

*Tensile strength, yield point, elongation in 2 in., reduction in area, and Young's modulus values are given for various temperatures throughout the range 75–800 deg. fahr. A typical set of stress-strain curves are given for one alloy, and detail curves showing the effects of temperature on the tensile strength, yield point, and reduction in area for all the materials discussed. An average curve and formula are given, showing the effects of temperature on Young's modulus for all aluminum alloys.*

*Data are presented to show how certain effects of temperature on aluminum alloys susceptible to heat treatment may be appreciably modified by still further heat treatment or artificial aging. A method is indicated for applying experimental results from a single lot of specimens to commercial-product average values, together with a complete table of recommended tensile-property values at various temperatures for the alloys tested.*

*The second part of the paper describes the original heating equipment, the alternate tests and alterations to equipment to determine and improve the temperature uniformity throughout the specimen; also the method of measuring the specimen temperatures during tensile tests, data being presented to substantiate the reliability of this method.*

*Consideration of the results of temperature-distribution tests made with the final arrangement of the heating equipment and the temperature-measuring equipment used for tensile tests, indicates that an accuracy of temperature measurement of plus or minus 1 per cent and a maximum temperature differential throughout the specimen of 10 deg. fahr. are obtained.*

## Part I[4]—Tests and Results

THE increasing use of cast aluminum alloys in structures or machines designed to function at elevated temperatures has demanded a better knowledge of the mechanical properties of the alloys throughout the temperature ranges obtaining. This need has been appreciated by many other investigators, as shown by the results appearing in the technical literature,[5] but a careful review of such data emphasizes the fact that in most cases the materials tested were non-commercial in this country, the methods used were open to serious criticism, or both. This conclusion seems to be in accordance with the findings of the Joint Committee of this Society and the American Society for Testing Materials, as shown by their symposium[6] and more recent report.[7] With all due respect to the valuable work done and planned by this committee, the authors are giving the results of their investigational work, qualifying it extensively by describing in careful detail the methods and apparatus used in testing and the treatment accorded the data obtained.

### Purpose and Scope of the Work

The work described in this paper had as its purpose the definition of the tensile properties of the more common casting alloys of aluminum throughout the elevated temperature ranges where they could be used satisfactorily. Data are given for ten different casting alloys, very pure aluminum, and for different heat treatments in the case of some of the alloys. In general, the tensile properties have been given throughout the temperature range 75–800 deg. fahr. In nearly all cases tests have been made at still higher temperatures, but the range just indicated covers the temperatures of interest to the designing engineer since the structural use of the alloys at temperatures above 800 deg. fahr. is not recommended.

The tests made were all of the so-called "short-time" type in which the specimen is pulled soon after temperature conditions have reached a practical equilibrium. Such a type of

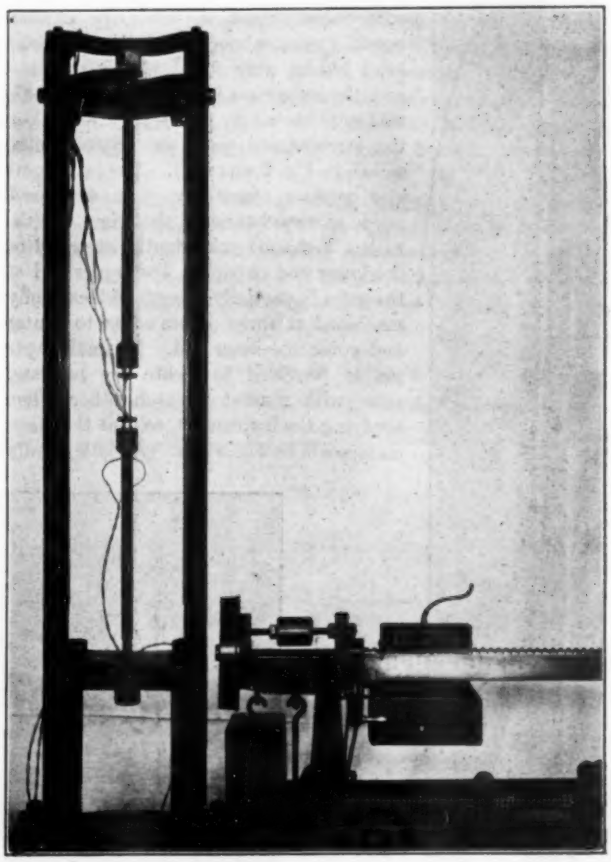

Fig. 1 Testing Machines With Specimen in Holders

[1] Chief Engineer of Tests, Aluminum Company of America.
[2] Testing Engineer, Aluminum Company of America.
[3] Chief of Pyrometric Division, Aluminum Company of America.
[4] By Messrs. Templin and Braglio.
[5] See bibliography at end of Part I of paper.
[6] "Symposium on Effect of Temperature upon the Properties of Metals," Proc. A.S.T.M., part II, vol. 24 (1924), p. 9.
[7] Progress Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Proc. A.S.T.M., part I, vol. 27 (1927), p. 139.

Presented at the Spring Meeting of the A.S.M.E., Pittsburgh, Pa., May 14 to 17, 1928.

high-temperature test has limitations, but gives a reasonable basis for comparing different alloys and materially assists in a better selection of material for use at the higher temperatures.

TABLE 1 PERCENTAGE CHEMICAL COMPOSITION OF CAST ALUMINUM ALLOYS USED IN TEMPERATURE-TENSILE TESTS

| Alloy | Si | Fe | Cu | Mn | Ca | Mg | Zn | Sn | Ni | Al (by diff.) |
|---|---|---|---|---|---|---|---|---|---|---|
| Pure aluminum, as cast. | 0.02 | 0.02 | 0.02 | .... | .... | .... | .... | .... | .... | 99.94 |
| No. 43, as cast......... | 5.07 | 0.55 | 0.22 | 0.05 | .... | .... | .... | .... | .... | 94.11 |
| No. 47, modified....... | 12.50 | 0.40 | 0.13 | 0.09 | .... | .... | .... | .... | .... | 86.88 |
| No. 106, as cast........ | 0.24 | 0.50 | 0.21 | 1.86 | .... | .... | .... | .... | .... | 97.19 |
| No. 109, as cast........ | 0.18 | 0.38 | 12.10 | 0.01 | .... | .... | .... | .... | .... | 87.33 |
| No. 112, as cast........ | 0.20 | 1.20 | 8.02 | 0.12 | .... | .... | 0.62 | 0.30 | .... | 89.53 |
| No. 122, as cast........ | 0.18 | 1.12 | 10.29 | 0.01 | .... | 0.22 | .... | .... | .... | 88.18 |
| No. 195, heat treated... | 0.75 | 0.57 | 4.40 | 0.02 | .... | .... | 0.25 | .... | .... | 94.01 |
| No. 196, heat treated... | 0.30 | 0.36 | 4.60 | .... | .... | 0.28 | .... | .... | .... | 94.46 |
| No. 142, as cast........ | 0.25 | 0.47 | 3.96 | 0.02 | .... | 1.33 | .... | .... | 2.30 | 91.67 |
| No. 142, heat treated... | 0.25 | 0.47 | 3.96 | 0.02 | .... | 1.33 | .... | .... | 2.30 | 91.67 |
| No. 121, as cast....... | 0.25 | 0.40 | 12.33 | 0.95 | .... | .... | .... | .... | .... | 86.07 |

## Methods and Apparatus Used

Before this work was done, much time and effort were spent in developing suitable apparatus for use in making the tests. Particulars of the furnace used, together with a brief description of its development and final calibration, are given in the second part of this paper by Mr. K. Marsh, who was responsible for many of the details of the final design, as well as for the electrical control panel. The tests were all made with a 1,000–10,000-lb. capacity Olsen wire testing machine, using the smaller capacity range whenever possible. Special head blocks were fitted to the machine and the extension holders with spherical-seat nuts shown in Fig. 1 provided. For the stress-strain tests the extensometer shown in Fig. 2 was used. The extensometer consists essentially of a steel rod inside of a steel tube of the same length, with a Y-shaped yoke rigidly attached to the lower end of each. The upper end of the tube is partially closed and carefully machined at three points so as to center and guide the inner rod. A small taper pin is provided to locate the rod and tube with respect to each other when applying the instrument, so that the lower clamps will be 2 in. apart. A guide rigidly clamped to the upper end of the top extension holder, is arranged so as to keep the instrument in proper position during use without restraining it from functioning as intended. This device proved very satisfactory for the materials tested, although it might not be sufficiently sensitive for similar tests of the ferrous metals due to their higher modulus values. The small clamps and screws at

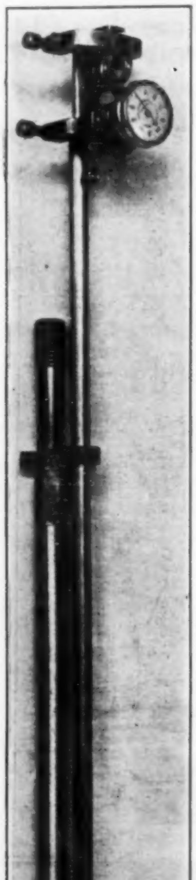

Fig. 2 Extensometer Used in Stress-Strain Tests

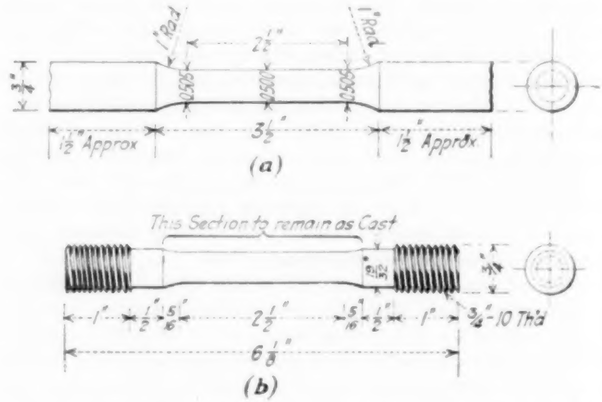


Fig. 3 Dimensions of Specimens as Cast (a) and as Machined (b)

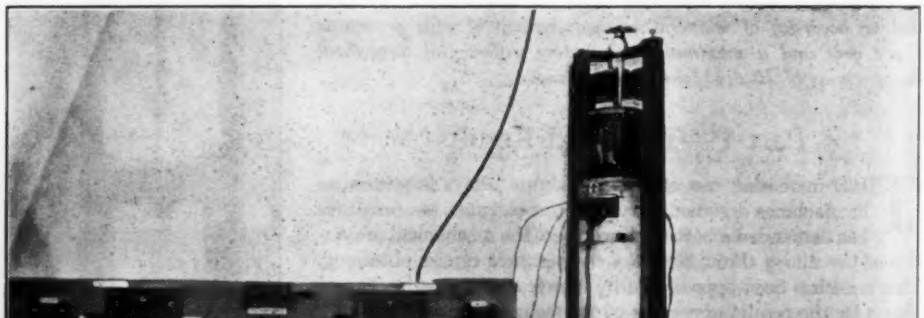

Fig. 4 Complete Assembly of Testing Machine, Furnaces, Control Panel, Temperature-Measuring Instruments, and Extensometer

the lower ends of the instrument are made of high-speed steel and gave no trouble due to oxidizing or annealing up to temperatures of 850 deg. fahr. The upper part of the instrument is a 2-in. Riehlé extensometer, one arm of which attaches to the outer tube and the other arm to the inner rod of the lower part of the instrument.

The specimens used were sand cast to the dimensions shown in Fig. 3(*a*), then machined to dimensions as shown in Fig. 3(*b*). These dimensions conform to the A.S.T.M. standard specimen for sand-cast metals. It should be noted that no machining

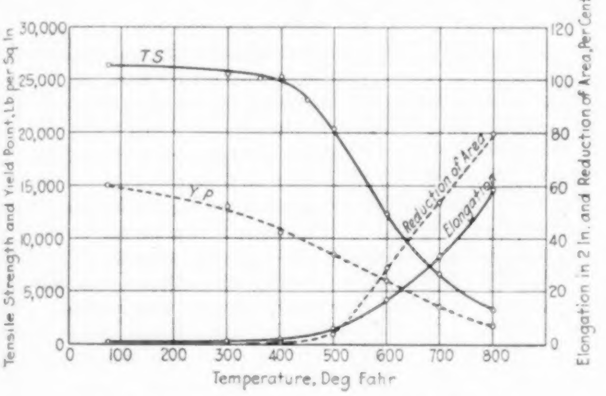


Fig. 5 Test Data of Alloy No. 109 as Cast

was done on the reduced portion or gage section of the specimens other than to file off occasional projections at the parting line of the mold. The specimens were cast under the supervision of Mr. R. S. Archer, at the Cleveland Works of the U. S. Aluminum Co. From 30 to 40 specimens were cast from the same lot of metal under carefully controlled conditions of melting, temperature, and casting so as to produce as uniform a set of specimens as possible for each alloy tested. In some instances such procedure gave mechanical properties at room temperature that were slightly higher than the commercial averages; in others they were slightly lower, but in no case was the deviation serious. Before making the tests at the higher temperatures each lot of specimens was carefully analyzed to make sure that their chemical composition closely approximated the nominal composition indicated for the alloy. The analyses of the specimens tested are given in Table 1.

In preparing a specimen for testing, the identification numbers were stenciled on the ends, the reduced section was measured, and two sets of 2-in. gage marks, staggered about $^1/_4$ in., were placed on it. The specimen was then screwed into the top extension holder and the holder held in a bench vise while the "beads" of the top and bottom thermocouples were clamped on the shoulders of the test specimen. Small pieces of asbestos paper were inserted between the thermocouple beads and the clamps to prevent radiation effects from the furnace walls. Fig. 1 shows a test specimen in the holders with thermocouples attached. The specimen was then screwed into the bottom specimen holder within the main furnace, and the top of the main furnace and the top end furnace replaced. The thermocouple wires were next connected to the recording instruments, the line current turned on, and the furnace rheostats adjusted, using the ammeter and calibration chart in order to obtain the desired temperatures in the main and end furnaces.

The approximate time required to heat the specimen to the desired temperature was about two hours. Occasionally it was necessary to make a slight adjustment of the rheostats so as to get the final testing temperature. The specimen was kept at the required temperature for about thirty minutes and then stressed to failure, the speed of the testing-machine pulling head being 0.107 in. per min. After the maximum load on the specimen was obtained and the specimen broken, it was removed from the furnace and the elongation and reduction of area measured.

For obtaining proportional-limit, yield-point, and modulus values the specimen was placed in the furnace with the special temperature-tensile extensometer attached to it. Upon reaching the proper temperature and remaining constant at that point for thirty minutes, stress-strain data were obtained by applying uniform increments of load and measuring the deformation by means of the special extensometer. The complete assembly of testing machine, furnaces, control panel, temperature-measuring instruments, and extensometer is shown in Fig. 4.

In most instances the tests at each temperature were made in triplicate, and the results of each test at a given temperature did not vary from the average of the three tests by more than ±4 per cent. This is evidence of uniformity both in the making of the specimens as well as in the test conditions. The temperatures recorded as being those at which the specimens were tested, are those obtained from the thermocouples clamped on the specimen, measured with the indicating galvanometer. The recording instrument was used as a check on the furnace conditions, for control purposes, and as a log of the time involved in making the tests.

## Discussion of Results

The tensile-strength, yield-point, reduction-of-area, and

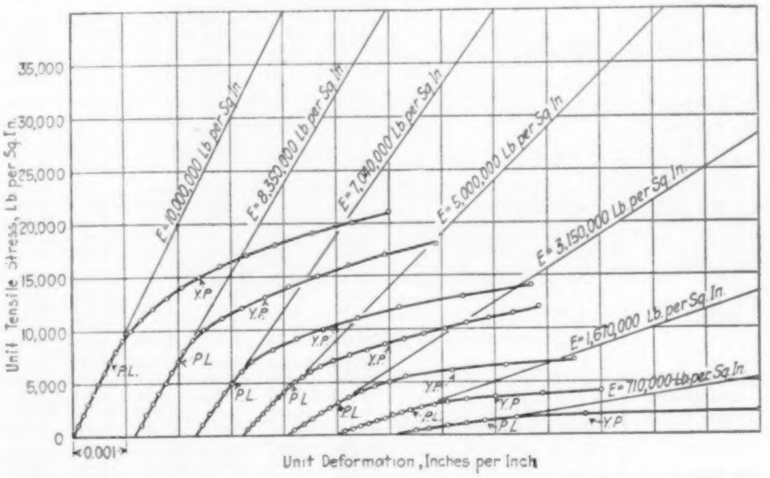


Fig. 6 Stress-Strain Curves for Alloy No. 109 (as Cast) at Various Temperatures

elongation values obtained in the case of each set of specimens tested were plotted as ordinates against temperature in degrees fahrenheit as abscissas. A typical set of such data for alloy No. 109 is shown in Fig. 5. The stress-strain curves obtained at the various temperatures for this same alloy are shown in Fig. 6, and are representative of similar data obtained from the tests of the other alloys. The yield-point values indicated on the curves correspond to the stresses at which the curves have departed from the initial modulus line produced by an amount equal to 0.1 per cent. This value is slightly less than that recommended by one of the authors in a recent paper before the American

TABLE 2 MECHANICAL PROPERTIES OF CAST ALUMINUM AND ALUMINUM ALLOYS AT DIFFERENT TEMPERATURES

| Alloy | Property | Temperature, Deg. Fahr. 75 | 200 | 300 | 400 | 500 | 600 | 700 | 800 |
|---|---|---|---|---|---|---|---|---|---|
| Pure aluminum as cast | T.S., lb. per sq. in. | 7350 | 6500 | 4800 | 3550 | 2500 | 1650 | 1050 | 600 |
| | Y.P., lb. per sq. in. | 2000 | 2000 | 1900 | 1800 | 1600 | .... | .... | .... |
| | % Elong. in 2 in. | 43.7 | 56.0 | 63.2 | 71.5 | 81.0 | 99.0 | 97.7 | 135.0 |
| | % Red. of area | 55.8 | 59.0 | 60.5 | 67.0 | 73.7 | 89.8 | 77.6 | 98.4 |
| | Young's modulus $\times 10^{-6}$ | 10.0 | 8.00 | 7.00 | 6.75 | 6.56 | ... | ... | .... |
| No. 43 as cast | T.S. lb. per sq. in. | 19000 | 17000 | 14600 | 11400 | 8400 | 6100 | 4200 | 2500 |
| | Y.P. lb. per sq. in. | 11000 | 9000 | 7000 | 6250 | 5000 | 4000 | 2500 | 1000 |
| | % Elong. in 2 in. | 4.75 | 9.00 | 12.2 | 15.6 | 21.2 | 23.9 | 26.6 | 32.3 |
| | % Red. of area | 4.20 | 10.5 | 15.3 | 21.6 | 33.9 | 39.7 | 45.4 | 51.7 |
| | Young's modulus $\times 10^{-6}$ | 10.0 | 9.25 | 8.35 | 6.44 | 5.00 | 3.62 | 2.04 | 1.00 |
| No. 47 as cast, modified | T.S., lb. per sq. in. | 26500 | 23850 | 19050 | 14250 | 10900 | 7850 | 5050 | 3100 |
| | Y.P., lb. per sq. in. | 10500 | 10000 | 9000 | 7250 | 5000 | 3500 | 2500 | 1500 |
| | % Elong. in 2 in. | 7.75 | 10.5 | 12.8 | 13.0 | 14.8 | 15.0 | 21.5 | 31.0 |
| | % Red. of area | 8.39 | 10.7 | 14.6 | 15.4 | 15.4 | 17.5 | 23.8 | 31.2 |
| | Young's modulus $\times 10^{-6}$ | 10.0 | 7.50 | 5.85 | 4.58 | 3.44 | 2.80 | 2.30 | 1.84 |
| No. 106 as cast | T.S., lb. per sq. in. | 19850 | 19150 | 17800 | 14800 | 12000 | 7500 | 5150 | 3650 |
| | Y.P., lb. per sq. in. | 7000 | 7000 | 6750 | 6500 | 5750 | 4750 | 3750 | 2750 |
| | % Elong. in 2 in. | 13.2 | 12.0 | 13.0 | 14.0 | 17.0 | 25.0 | 32.9 | 33.0 |
| | % Red. of area | 18.6 | 17.3 | 18.1 | 19.8 | 25.9 | 33.8 | 40.6 | 43.1 |
| | Young's modulus $\times 10^{-6}$ | 10.0 | 6.67 | 5.85 | 5.30 | 5.00 | 4.10 | 2.35 | 1.40 |
| No. 109 as cast | T.S., lb. per sq. in. | 24500 | 24200 | 23900 | 23100 | 18900 | 11500 | 6150 | 3200 |
| | Y.P., lb. per sq. in. | 14000 | 13000 | 12000 | 10000 | 7750 | 5500 | 3250 | 1500 |
| | % Elong. in 2 in. | 1.00 | 1.25 | 1.50 | 1.83 | 4.38 | 16.8 | 33.0 | 58.2 |
| | % Red. of area | 0.00 | 0.00 | 0.00 | 1.04 | 4.09 | 28.8 | 53.2 | 79.6 |
| | Young's modulus $\times 10^{-6}$ | 10.0 | 9.20 | 8.35 | 7.00 | 5.00 | 3.15 | 1.70 | 0.70 |
| No. 112 as cast | T.S., lb. per sq. in. | 21750 | 21100 | 19750 | 17500 | 16250 | 11000 | 5650 | 3500 |
| | Y.P., lb. per sq. in. | 12000 | 11750 | 11000 | 10750 | 10750 | 7250 | 3750 | 2250 |
| | % Elong. in 2 in. | 1.00 | 1.00 | 2.00 | 1.00 | 1.00 | 2.50 | 11.8 | 17.5 |
| | % Red. of area | 0.00 | 0.00 | 2.24 | 0.00 | 0.00 | 1.94 | 18.3 | 23.3 |
| | Young's modulus $\times 10^{-6}$ | 10.0 | 8.30 | 6.67 | 5.00 | 4.55 | 3.00 | 1.56 | 0.83 |
| No. 112 as cast and aged[1] | T.S., lb. per sq. in. | 28400 | 27500 | 25000 | 21500 | 17750 | 12000 | 6000 | 3750 |
| | Y.P., lb. per sq. in. | 15000 | 13750 | 12500 | 12000 | 10500 | 8250 | 4250 | 2500 |
| | % Elong. in 2 in. | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 2.50 | 11.8 | 17.5 |
| | % Red. of area | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.94 | 18.3 | 23.3 |
| | Young's modulus $\times 10^{-6}$ | 10.0 | 8.35 | 6.67 | 5.00 | 4.00 | 3.00 | 1.56 | 0.83 |
| No. 122 as cast | T.S., lb. per sq. in. | 26500 | 25500 | 24750 | 23500 | 21250 | 12850 | 6100 | 3600 |
| | Y.P., lb. per sq. in. | 20500 | 18250 | 16250 | 14000 | 11750 | 9000 | 4250 | 2250 |
| | % Elong. in 2 in. | 0.50 | 0.50 | 1.00 | 1.00 | 1.50 | 7.50 | 25.7 | 42.5 |
| | % Red. of area | 0.79 | 1.00 | 1.00 | 1.00 | 1.18 | 8.31 | 46.4 | 66.7 |
| | Young's modulus $\times 10^{-6}$ | 10.0 | 9.10 | 7.70 | 5.00 | 4.68 | 4.00 | 2.50 | 1.00 |
| No. 142 as cast | T.S., lb. per sq. in. | 27650 | 26800 | 26300 | 25300 | 22100 | 14900 | 7350 | 3600 |
| | Y.P., lb. per sq. in. | 23250 | 21500 | 20000 | 18750 | 16250 | 10500 | 4500 | 1750 |
| | % Elong. in 2 in. | 0.50 | 0.50 | 0.50 | 0.50 | 1.00 | 4.00 | 17.0 | 58.5 |
| | % Red. of area | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.41 | 19.1 | 46.9 |
| | Young's modulus $\times 10^{-6}$ | 10.00 | 9.50 | 9.00 | 8.20 | 6.67 | 5.00 | 3.30 | 1.80 |
| No. 142 heat treated | T.S., lb. per sq. in. | 37150 | 35750 | 34500 | 33000 | 26100 | 16250 | 8250 | 3200 |
| | Y.P., lb. per sq. in. | 29000 | 28500 | 27500 | 25000 | 19000 | 7000 | 3000 | 1500 |
| | % Elong. in 2 in. | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12.5 | 44.0 |
| | % Red. of area | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.3 | 39.2 |
| | Young's modulus $\times 10^{-5}$ | 10.00 | 8.00 | 6.67 | 6.25 | 5.56 | 2.55 | 1.67 | 0.83 |
| No. 195 heat treated | T.S., lb. per sq. in. | 31000 | 29500 | 30500 | 33200 | 18600 | 9450 | 4000 | 2650 |
| | Y.P., lb. per sq. in. | 13500 | 11500 | 12250 | 14250 | 12250 | 7000 | 2750 | 1500 |
| | % Elong. in 2 in. | 7.17 | 9.00 | 4.50 | 1.67 | 5.38 | 16.0 | 46.0 | 71.0 |
| | % Red. of area | 6.30 | 8.88 | 6.90 | 0.00 | 6.20 | 26.7 | 52.3 | 65.0 |
| | Young's modulus $\times 10^{-6}$ | 10.00 | 8.00 | 7.00 | 6.67 | 5.60 | 4.25 | 2.35 | 0.75 |
| No. 195 heat treated and aged[2] | T.S., lb. per sq. in. | 35800 | 32750 | 29800 | 24700 | 15675 | 7550 | 3800 | 2650 |
| | Y.P., lb. per sq. in. | 24000 | 22250 | 20500 | 18000 | 12000 | 6000 | 2750 | 1500 |
| | % Elong. in 2 in. | 1.75 | 2.00 | 3.50 | 4.00 | 6.17 | 19.0 | 26.0 | 51.0 |
| | % Red. of area | 1.76 | 2.00 | 3.13 | 6.20 | 14.4 | 31.3 | 51.1 | 65.0 |
| | Young's modulus $\times 10^{-6}$ | 10.0 | 9.70 | 9.25 | 8.20 | 7.00 | 4.45 | 2.15 | 0.75 |
| No. 196 heat treated | T.S., lb. per sq. in. | 41550 | 38500 | 32050 | 39550 | 25250 | 12000 | 4600 | 2500 |
| | Y.P., lb. per sq. in. | 28000 | 20500 | 16000 | 21000 | 14000 | 7000 | 3250 | 1500 |
| | % Elong. in 2 in. | 3.50 | 4.50 | 2.83 | 1.50 | 3.83 | 16.0 | 54.0 | 97.0 |
| | % Red. of area | 4.48 | 6.53 | 4.29 | 0.79 | 6.18 | 28.6 | 67.8 | 82.8 |
| | Young's modulus $\times 10^{-6}$ | 10.00 | 8.75 | 6.67 | 5.50 | 4.55 | 3.35 | 1.50 | 1.00 |
| No. 196 heat treated and aged[3] | T.S., lb. per sq. in. | 36270 | 34000 | 31000 | 26950 | 19350 | 12000 | 4600 | 2500 |
| | Y.P., lb. per sq. in. | 29000 | 26250 | 23000 | 22000 | 15000 | 7000 | 3250 | 1500 |
| | % Elong. in 2 in. | 1.50 | 2.00 | 2.50 | 5.00 | 4.00 | 16.0 | 54.0 | 97.0 |
| | % Red. of area | 0.00 | 1.00 | 1.98 | 5.66 | 6.17 | 28.6 | 67.8 | 82.8 |
| | Young's modulus $\times 10^{-6}$ | 10.00 | 9.15 | 8.10 | 7.00 | 5.60 | 3.35 | 1.50 | 1.00 |
| No. 121 as cast | T.S., lb. per sq. in. | 24400 | 24300 | 24200 | 23650 | 23450 | 16700 | 11000 | 6725 |
| | Y.P., lb. per sq. in. | 16000 | 15000 | 14000 | 12500 | 11500 | 8000 | 5500 | 3250 |
| | % Elong. in 2 in. | 1.00 | 1.00 | 1.00 | 1.00 | 2.50 | 10.0 | 17.5 | 25.5 |
| | % Red. of area | 0.00 | 0.00 | 0.00 | 0.79 | 1.17 | 17.7 | 26.2 | 40.5 |
| | Young's modulus $\times 10^{-6}$ | 10.00 | 9.25 | 8.33 | 6.80 | 5.00 | 2.50 | 2.00 | 1.43 |

[1] Aged 48 hours at 400 deg. fahr.
[2] Aged one week at 400 deg. fahr.
[3] Aged 113 hours at 200 deg. cent. (392 deg. fahr.).

**Society for Testing Materials.[8] It was considered that the use of such an empirical scheme for determining this property might answer for comparative purposes in the present investigation. Similar stress-strain curves were determined for all of the other lots of specimens tested, but on account of space limitations they have not been included here. The curves showing the effects of temperature on the tensile strength, yield point, reduction of area, and elongation for the other alloys are given in Figs. 8 to 21, inclusive. In all of these curves the points indicated as defining the curves are the actual test results in every case, but are not in strict agreement with the values shown in Table 2, as will be explained later.**

**It was found from the tests that the values of the modulus of elasticity obtained were appreciably affected by temperature as well as by the precision of the extensometer and the temperature-measuring apparatus used. With this in mind and after a careful review of the modulus values obtained from all the tests, it seemed advisable to average the values for all the materials at each temperature, giving the resulting curve shown in Fig. 22. Reference to this curve shows that these average values approximate very closely a straight line which is defined by the formula:**

$$E = 11{,}200{,}000\left(1 - \frac{T}{890}\right)$$

**in which $E$ = Young's modulus of elasticity in lb. per sq. in., and**

**$T$ = temperature in degrees fahrenheit throughout the range 0–890 deg. fahr.**

**From a comparison of the tensile-strength and yield-point curves shown for the various alloys tested, it is clearly seen that these properties decrease with increasing temperature. Certain characteristics of the test results obtained from these alloys permit them to be divided into three groups. The first group consists of No. 7A or very pure aluminum, and Nos. 106, 47, and 43 alloys, all of which are low in copper. The second group consists of Nos. 122, 109, and 142 both in the "as cast" and "heat treated" conditions, and No. 121; this group containing the alloys which are apparently best suited for use at the higher temperatures and which have a higher copper content. The third group consists of Nos. 195, 196, and 112 alloys, and contains those alloys that do not follow the general trend of the previous groups in their behavior at the various temperatures. Results are also shown for the alloys of this group after further artificial aging, whereupon the characteristics peculiar to this group as shown in the preliminary tests are largely eliminated.**

**In general, the first group of alloys, including the very pure**

[8] "Methods for Determining the Tensile Properties of Thin Sheet Metals," by R. L. Templin. Proc. A.S.T.M., part II, vol. 27 (1927), p. 235.

aluminum, shows an appreciable effect of temperature on their mechanical properties beginning at or near room temperature. The second group of alloys does not show such appreciable effects until temperatures in the neighborhood of 400 to 500 deg. fahr. are reached, after which the temperature effects are rather pronounced.

The third group of alloys includes essentially those which are susceptible to artificial aging or secondary heat treatment, and when the tests of such alloys are made at or near temperatures corresponding to their aging temperatures, marked differences are observed in the test results obtained. This is very clearly shown in Figs. 12, 17, and 19. However, the "kinks" in the tensile-strength and yield-point curves for these alloys are almost eliminated by artificial aging of the specimens, at suitable temperatures, subsequent to the initial heat treatment, as shown in Figs. 13, 18, and 20. It will be noted that the curves just referred to are in many respects similar to those obtained from the tests of the second group of alloys previously referred to. Specific consideration has been given to these apparent irregularities in the temperature-tensile curve because they have been observed in similar data reported by other investigators, unaccompanied by adequate, if any, explanation. The present data would appear to emphasize the necessity for further tests of metals that show similar characteristics when tested at elevated temperatures.

In applying the results obtained from the tests just discussed to commercial product of the same nominal composition, a procedure was followed that appears to be somewhat different from any hitherto indicated by other investigators. From the results of many routine tests—in some cases thousands—obtained from the control laboratories of our casting plants, average values for the tensile properties of a given alloy were obtained. These values were accepted as representative of the various alloys, and are indicated in Table 2 as being the properties at 75 deg. fahr. or room temperature. The tensile properties obtained from the results of the investigational work on the representative lots of specimens for each alloy were then replotted in the form of ratio curves to show the ratio of the property at a given high temperature to that of the same property at room temperature, expressing the result as a percentage value. For example, the tensile strength of a given alloy as determined from the experimental tests at 500 deg. fahr. may have been found to be 80 per cent of the tensile-strength value for similar specimens from the same lot tested at room temperature. In order to obtain a satisfactory value for tensile strength for the commercial run of material of this same alloy, at 500 deg. fahr., the average tensile strength obtained from routine commercial tests has been multiplied by 0.80 to obtain the desired value. This procedure has been followed in the case of each material tested, for the various temperatures indicated, and the results are given in Table 2. It will be observed upon comparing the values in this table with the actual test results obtained in the curves, Figs. 5 to 22, that no serious discrepancies occur. Furthermore, the values indicated in Table 2 are those recommended for consideration in determining the suitability of the various alloys for use at temperatures ranging from 75 to 800 deg. fahr.

In using the data given in Table 2, it must be remembered that these values were obtained by the "short-time" method and therefore may not be in strict accordance with similar mechanical-property values that would be found when using a greater time factor during testing. In selecting actual design values for the different alloys considerable engineering judgment in choosing proper safety factors is necessary when using mechanical-property values obtained from the short-time tests. The values indicated, however, would appear to furnish a reasonable basis for comparing the various alloys investigated.

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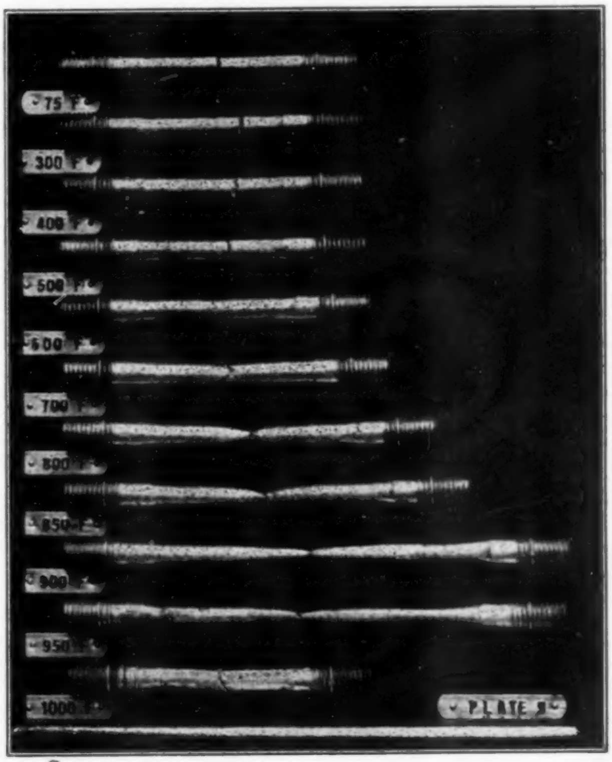


FIG. 7 TYPES OF FRACTURE OF ALLOY NO. 109 SPECIMENS AT VARIOUS TEMPERATURES


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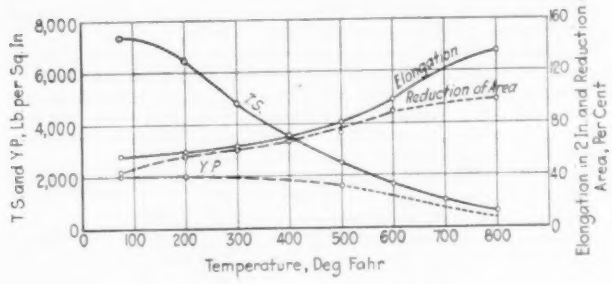


Fig. 8 99.94 Aluminum as cast

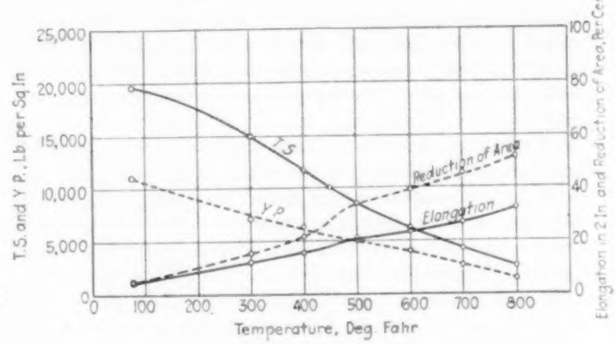


Fig. 9 Alloy No. 43 as cast

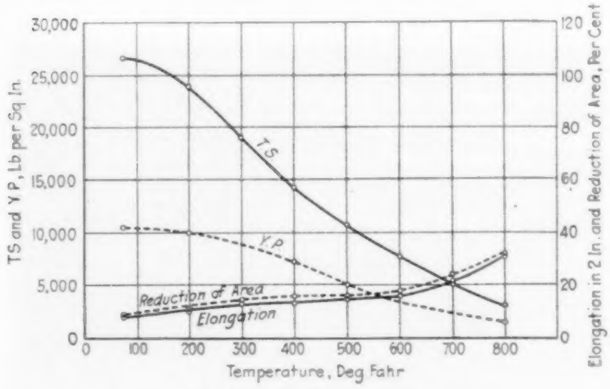


Fig. 10 Alloy No. 47 as cast

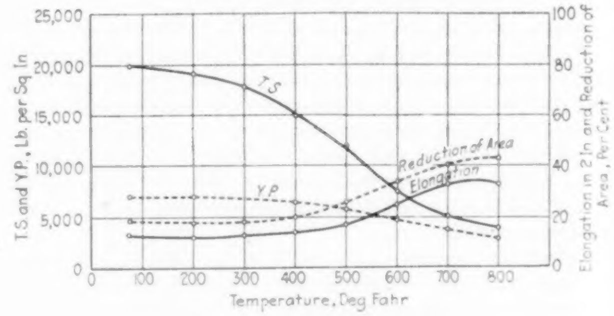


Fig. 11 Alloy No. 106 as cast

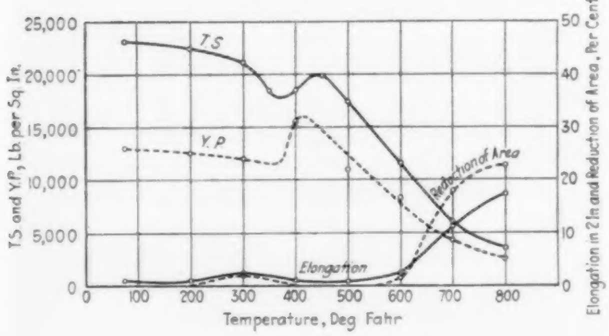


Fig. 12 Alloy No. 112 as cast

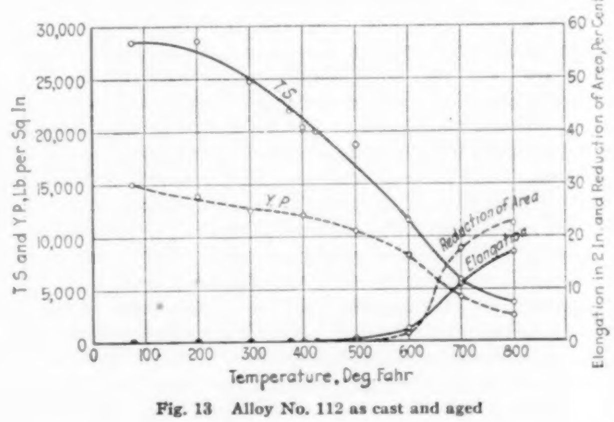


Fig. 13 Alloy No. 112 as cast and aged

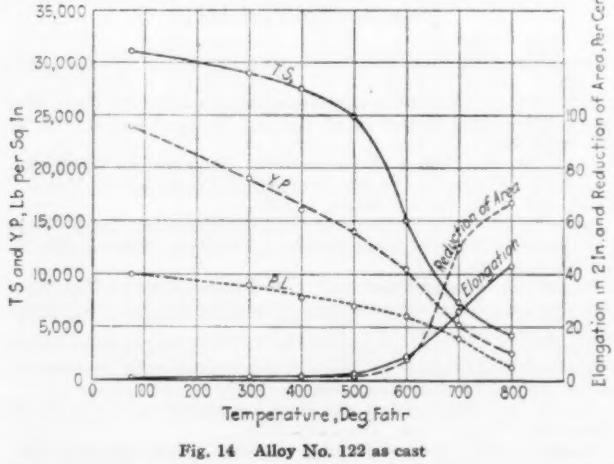


Fig. 14 Alloy No. 122 as cast

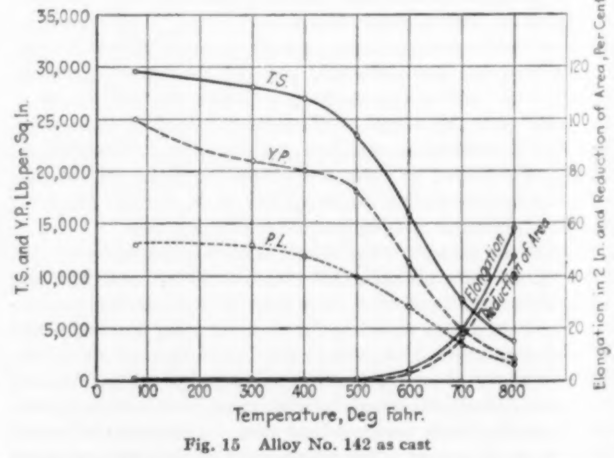


Fig. 15 Alloy No. 142 as cast

FIGS. 8 TO 15 CURVES SHOWING EFFECTS OF TEMPERATURE ON TENSILE STRENGTH, YIELD POINT, REDUCTION OF AREA, AND ELONGATION FOR VARIOUS ALLOYS

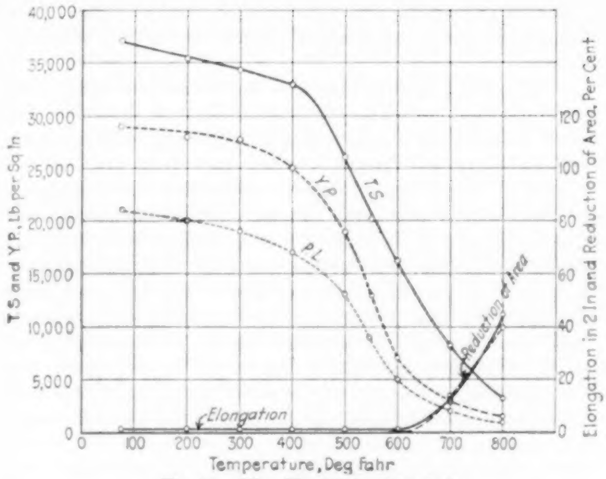


Fig. 16 Alloy No. 142 heat treated

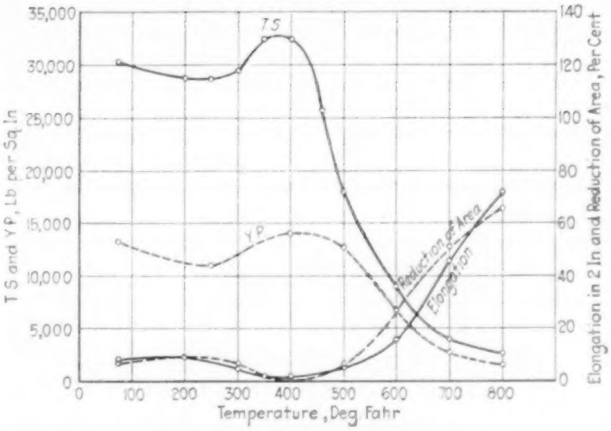


Fig. 17 Alloy No. 195 heat treated

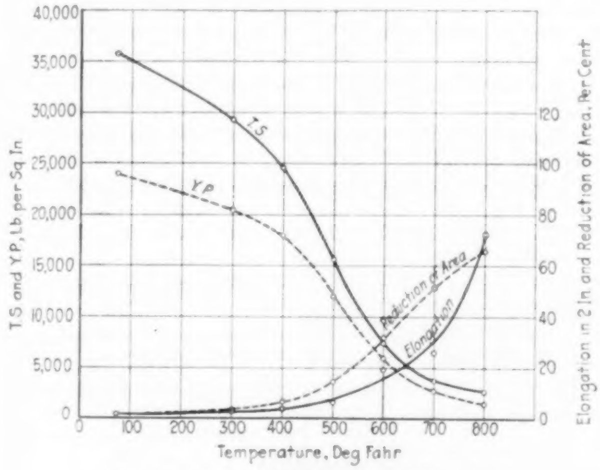


Fig. 18 Alloy No. 195 heat treated and aged

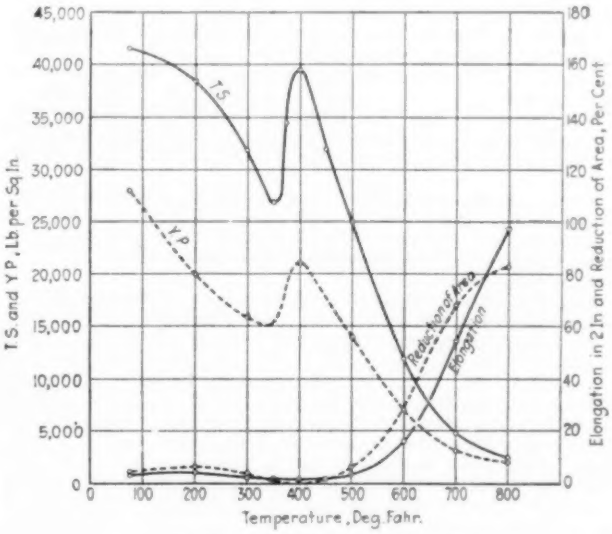


Fig. 19 Alloy No. 196 heat treated

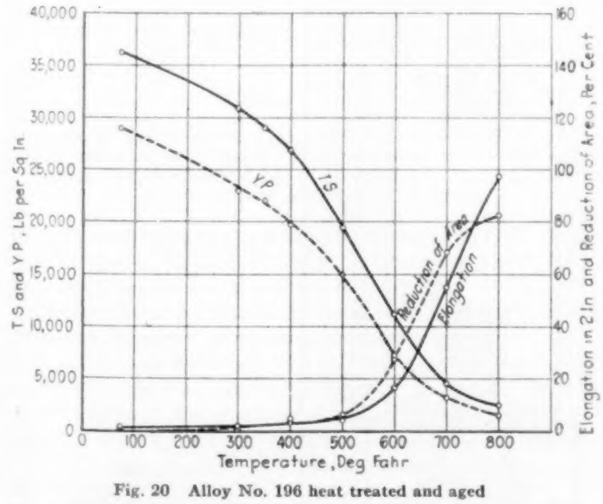


Fig. 20 Alloy No. 196 heat treated and aged

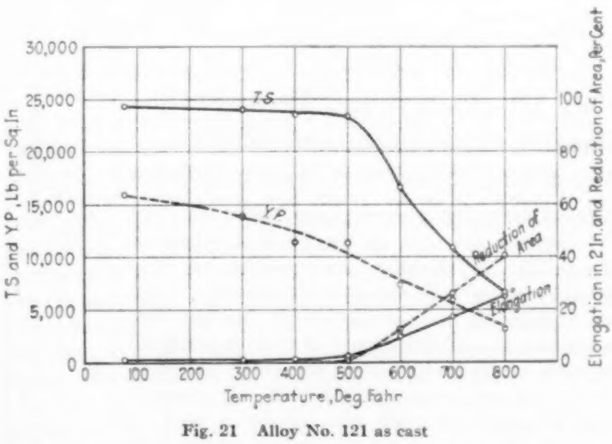


Fig. 21 Alloy No. 121 as cast

FIGS. 16 TO 21 CURVES SHOWING EFFECTS OF TEMPERATURE ON TENSILE STRENGTH, YIELD POINT, REDUCTION OF AREA, AND ELONGATION FOR VARIOUS ALLOYS

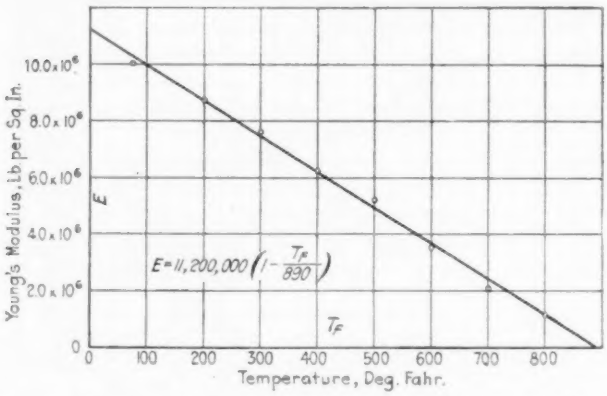


FIG. 22 AVERAGE VALUES OF MODULUS OF ELASTICITY FOR ALL MATERIALS TESTED AT VARIOUS TEMPERATURES

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# Part II[9]—Design and Testing of the Heating Equipment, and Method of Measuring Specimen Temperatures

CONSIDERABLE discrepancy seems to exist between the data on the physical properties of metals at elevated temperatures as published by several independent investigators. There are undoubtedly several reasons for this, but from a consideration of the apparatus used as described by some of the investigators who have published data, it seems quite possible that one cause is directly associated with the apparatus used to maintain the specimens at the desired temperature and the method of determining the temperature of the specimen. In some cases the heating equipment is inadequate to produce a uniform temperature throughout the specimen or test part of the specimen being subjected to the test, and in other cases it is doubtful if the temperature of the specimen is correctly measured.

The Technical Direction Bureau of the Aluminum Company of America has conducted a large number of tests to determine the effect of temperature on the tensile properties of aluminum and aluminum alloys, the results of which have been given in the first part of this paper. Before commencing these tests much time and thought was given to the construction of suitable heating equipment, and on testing it to determine the temperature uniformity of the specimen and the accuracy of the measurement of specimen temperatures, and this Part II has been written to substantiate the data presented in the first part of the paper.

Also, since entirely satisfactory results were not obtained with the apparatus originally constructed, a brief description of the preliminary tests and alterations to the apparatus has been included in order that some of the possibilities of adverse conditions may be realized by others.

The original furnace was constructed in the fall of 1923 and was arranged for the use of an oil-bath heating medium for moderate temperatures and a salt-bath medium for higher temperatures. The general arrangement of the furnace and bath container is shown in Fig. 23.

Before the furnace was placed in service it was desired to make certain tests to determine the relation between the specimen temperature and the bath temperature, and the temperature uniformity throughout the specimen.

In order to determine the temperature uniformity throughout

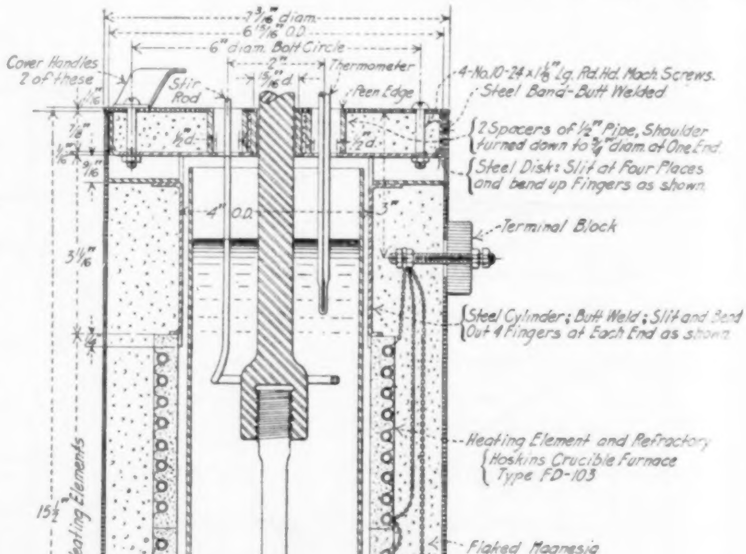


FIG. 23 ASSEMBLY DRAWING OF ORIGINAL FURNACE

[9] By Kirtland Marsh.

the specimen, three thermocouples made up of No. 20 B. & S. gage iron-constantan asbestos-insulated thermoelement wire were inserted in the specimen as shown in Fig. 24(*a*). Three diametrical holes $^1/_8$ in. in diameter were drilled through the specimen, one in each shoulder and one at the center of the reduced section, and in addition three radial holes were drilled perpendicular to them. The asbestos-insulated thermocouples were threaded through these diametrical holes until the hot junction was at the center of the specimen, care being taken to keep the asbestos insulation intact so that it would extend inside the surface of the specimen. In this manner the thermoelements were prevented from touching the specimen except at the hot junction, and they were protected from the higher-temperature atmosphere around the specimen. When the hot junction of each couple was properly centered, a soft aluminum rivet was driven into each radial hole so as to press the hot junctions firmly against the metal of the specimen and thus make good thermal contact with it.

It was felt that with the specimen thermocouples inserted in this manner, the temperature of the hot junction of the thermocouple—which is the temperature actually measured—would agree with the temperature of the center of the specimen at that point to within a small fraction of 1 deg. fahr. The thermoelement wire was of relatively small cross-section and therefore of small mass; the hot junction was small, only sufficient silver solder being used to securely connect the two elements; the asbestos insulation reduced the heat flow from the hotter medium surrounding the specimen to the thermoelement wires, and therefore reduced the conduction of heat along the elements to the hot junctions; good thermal contact between the hot junction of the thermocouple and the specimen was obtained; the asbestos insulation practically sealed the ends of the diametrical hole in the specimen and thereby eliminated any circulation of the heating medium around the hot junction. No actual tests were made to determine how closely the thermocouples measured the temperature of the specimen at the points of insertion, but from a consideration of the methods used and precautions taken, it is believed that any one familiar with

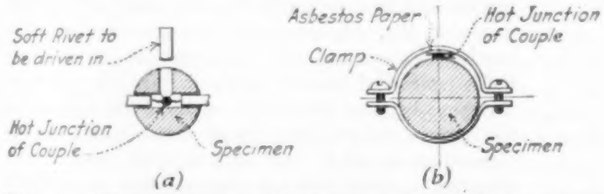


FIG. 24 CROSS-SECTIONS OF SPECIMEN SHOWING (*a*) METHOD OF INSERTING THERMOCOUPLES AND (*b*) METHOD OF CLAMPING THERMOCOUPLE TO SHOULDER OF SPECIMEN

accurate temperature measurements will agree that the temperature of the hot junction and of the specimen probably did not differ by more than a small fraction of 1 deg. fahr.

Previous to these tests the thermoelement wire was calibrated at the freezing points of tin, zinc, and aluminum.

Since it is impossible to drill a hole for a thermocouple at the center of a specimen to be pulled, and impractical to insert thermocouples in the shoulders of each specimen, it was highly desirable that some other means of measuring the specimen temperature be devised. It was decided to clamp a couple against the shoulder of the specimen and compare the temperatures as measured by the clamped-on couple with the temperatures measured by a couple inserted in the same shoulder as described above. A thermocouple was made up of the same thermoelement wire as used for the inserted couples, namely, No. 20 B. & S. gage asbestos-insulated iron-constantan wire. After being soldered, the hot junction was slightly flattened by tapping it lightly with a small hammer. A small band or clamp was made of two pieces of about No. 14 gage sheet steel $^1/_4$ in. wide and held together by two screws. In clamping the couple to the specimen, the hot junction was laid against the specimen and a piece of asbestos paper placed between the steel clamp and the hot junction. Fig. 24(*b*) shows the method of clamping the couple to the specimen.

It was found that the clamped-on couple agreed almost ex-

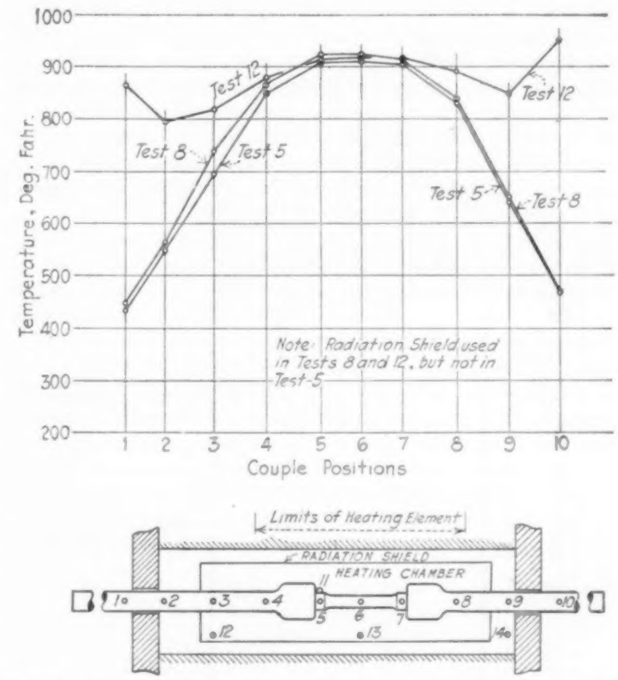


FIG. 25 DIAGRAM OF HEATING EQUIPMENT SHOWING LOCATION OF THERMOCOUPLES AND TEMPERATURE-DISTRIBUTION CURVES FOR TESTS 5, 8, AND 12

actly with the inserted couple, the difference being less than 0.5 deg. fahr. as measured on a precision potentiometer.

The first few tests were made with the specimen heated in air and later in an oil bath. No tests were made with the specimen in a salt bath due to the practical impossibility of protecting the couples from the bath.

Surprisingly good temperature uniformity throughout the specimen was obtained when the specimen was heated in air.

Accordingly, since the use of an oil or salt bath is attended with considerably greater risk to the operator, and the manipulation of the apparatus is considerably more complicated and the fracture is obscured with oil or salt, it was decided to eliminate the use of an oil or salt bath and employ a heating medium of air only. The bath holder with the stuffing box on the bottom end as shown in Fig. 23 was therefore removed.

After this furnace was placed in service, it was soon learned that a specimen pulled at a sufficiently high temperature to give an elongation of 100 to 150 per cent in two inches was subjected to considerable cooling as the top of the specimen was drawn toward the top of the furnace. The reason for this was obvious. In test 5 (see Fig. 25), with a constant specimen temperature of 910 deg. fahr., the temperature of the air surrounding the specimen was about 100 deg. fahr. higher than the specimen temperature. The conduction of heat along the specimen holders was so great that a temperature differential of 100 deg. fahr. between the specimen and the surrounding air was necessary before the heat transfer from the air to the specimen and specimen holders equaled the heat loss through the holders.

The data from test 5, Table 3, show the relation between the temperature of the specimen, holders, and the furnace atmosphere.

It was believed that the temperature at the center of the specimen would be affected as well as the temperature of the top shoulder, and as such a condition would be highly undesirable, particularly since the temperature at the center of the specimen was not measured, it was decided that such alterations to the equipment as were necessary should be made to eliminate these conditions.

A radiation shield consisting of a sheet-iron cylinder with open ends was tried out with the hope of producing a more uniform temperature, but without success as shown by test 8, Fig. 25.

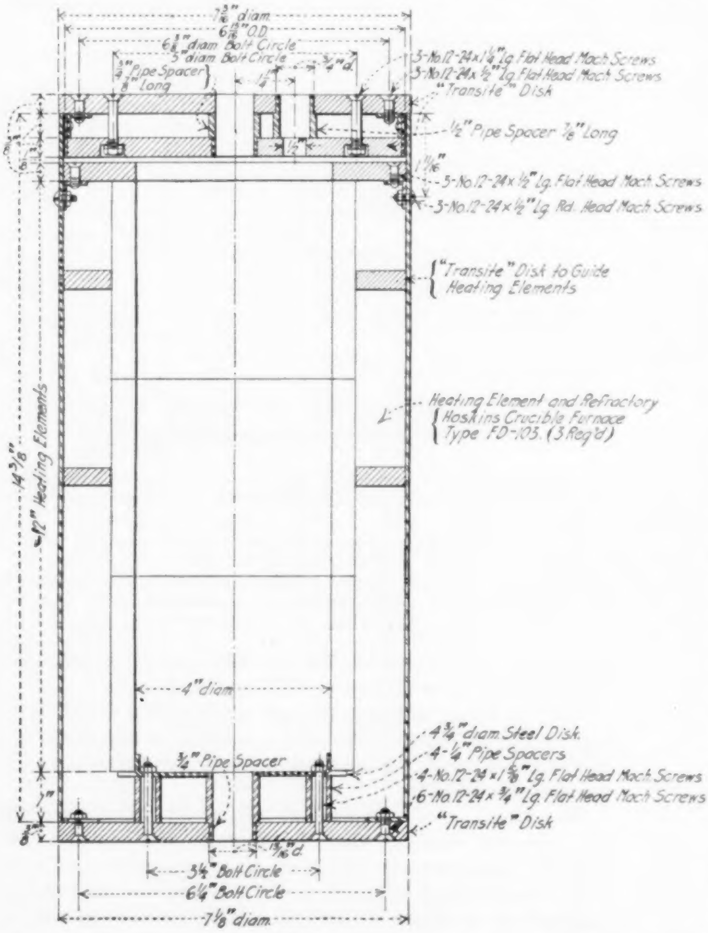


Fig. 26 Drawing Showing Principal Changes to Main Furnace After Test 12

After considerable study it was decided to provide additional heating elements around those parts of the specimen holders that extended beyond the ends of the main furnace in order that the heat conducted along the holders and dissipated into the air and the heads of the testing machine could be absorbed from the additional heating elements, or "end heaters" as they were subsequently termed, instead of being drawn from the specimen and the atmosphere surrounding those parts of the holders in the main furnace. For this purpose two Type 70-3 multiple-unit electric furnaces with a rating of 2.3 amperes on 220 volts were obtained and placed around the holders at the end of the main furnace.

No assembly drawing or photograph of the main furnace as originally constructed or with the end heaters is available, but the external appearance is practically the same as shown in the photograph of the final arrangement, Fig. 4.

Subsequent to the addition of the end heaters, further tests were made using the three inserted couples and the one clamped-on couple for measuring the specimen temperatures, together with several additional couples to measure the temperature of the holders and the furnace atmosphere. The couples in the holders were made up in the same manner as the couples inserted in the specimen, and were inserted in the holders in the same manner except that No. 6 iron machine screws instead of rivets were used to press the hot junctions against the interior of the holders.

These tests, of which test 12 (see Fig. 25) is typical, showed that conditions had been considerably improved but that there was still a considerable drop in temperature along the specimen holders between the ends of the specimen and the ends of the main furnace, even though the temperature of those parts of the holders in the end heaters was nearly up to the specimen temperature. This was attributed in part to the fact that the heating elements in the main furnace extended over a length of only 8 in., whereas the heating chamber was $13^1/_2$ in. long, with the result that there was considerable length between the ends of these heating elements and those in the end heaters. The main furnace was then reconstructed; the principal changes, shown in Fig. 26, consisted of spreading the same heating element out over the length of three refractories instead of two as shown in Fig. 23, reducing the space between the bottom of the cover and top of the furnace, and replacing the sheet-steel tops and bottoms of cover and furnace with asbestos board. The specimen couples were not changed, but those in the holders were relocated and additional couples inserted.

Fig. 27 shows diagrammatically the arrangement of the two end heaters and the main furnace, as well as the relocation of the thermocouples in the specimen and holders.

The addition of the end heaters increased the amount of control equipment required, and in order to facilitate the operation of the furnace, a control board was designed and constructed. Fig. 28 shows the wiring diagram of this control board, and indicates the apparatus mounted thereon.

TABLE 3 DATA FROM TEMPERATURE-DISTRIBUTION TESTS

(Specimen temperatures are printed in bold-face figures.)

| Test no. | Fig. no. | Couple No. 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | Temp. diff. throughout specimen, deg. fahr. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temperature, Deg. Fahr. | | | | | | | | | | | | | | | | | | |
| 5 | 25 | 433 | 547 | 695 | 848 | **908** | **910** | **904** | 829 | 640 | 468 | **911** | 714 | 1011 | 739 | ... | ... | ... | ... | 6 |
| 8 | 25 | 448 | 563 | 719 | 866 | **924** | **924** | **914** | 839 | 650 | 470 | **929** | 768 | 1021 | 770 | ... | ... | ... | ... | 10 |
| 12 | 25 | 864 | 795 | 818 | 879 | **914** | **918** | **917** | 891 | 848 | 950 | (a) | 786 | 972 | 808 | 1199 | 1220 | ... | ... | 4 |
| 13 | 27 | 291 | 283 | 287 | 294 | **298** | **298** | **296** | **294** | 290 | 294 | 300 | **298** | 381 | 276 | 305 | 314 | 286 | 376 | 4 |
| 14 | 27 | 605 | 571 | 580 | 600 | 614 | **616** | **610** | **604** | 595 | 604 | 631 | **616** | 697 | 554 | 621 | 636 | 580 | 705 | 12 |
| 15 | 27 | 668 | 588 | 567 | 571 | 579 | **582** | **580** | **580** | 582 | 626 | 700 | **582** | 770 | 522 | 576 | 591 | 549 | 781 | 2 |
| 16 | 27 | 1106 | 930 | 892 | 908 | 928 | **934** | **930** | **928** | 931 | 1016 | 1171 | **934** | 1153 | 842 | 926 | 943 | 892 | 1213 | 6 |

(a) Clamped-on couple short-circuited in this test.

The heating element in the main furnace was divided into two sections, so arranged that they could be connected in series or parallel. The two end heaters were also arranged so that they

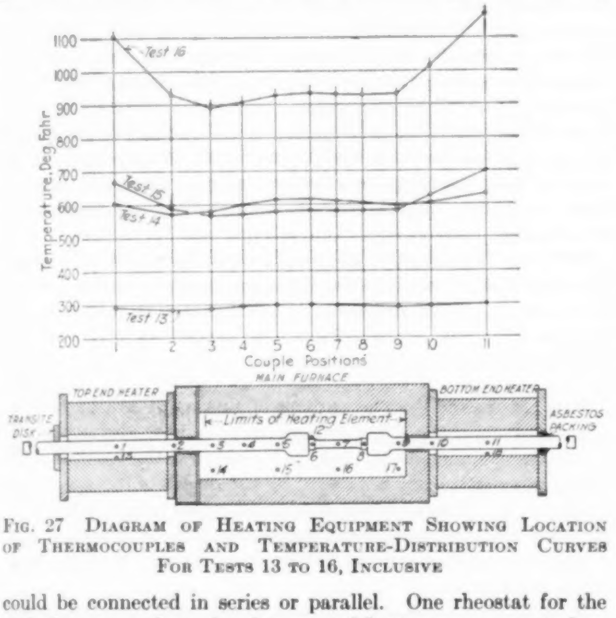


FIG. 27 DIAGRAM OF HEATING EQUIPMENT SHOWING LOCATION OF THERMOCOUPLES AND TEMPERATURE-DISTRIBUTION CURVES FOR TESTS 13 TO 16, INCLUSIVE

could be connected in series or parallel. One rheostat for the main furnace and one for the two end heaters were mounted on the board.

Following the last-mentioned changes to the furnace and the construction of the control board, further tests were made. The current through the main furnace was adjusted to give the desired specimen temperature, but the current through the end heaters was adjusted to produce and maintain different conditions in an effort to determine which method of control would produce the most uniform temperature throughout the length of specimen and those parts of the holders in the main furnace. During the first test of this series, No. 13, the current through the end heaters was adjusted to make the temperature of the specimen holders in the end heaters as measured by couples 1 and 11 (see curve sheet, Fig. 27) agree with the specimen temperature of 296 deg. fahr., couple No. 7. However, it was found that the temperature of No. 1 couple was above and that of No. 11 couple below the specimen temperature, and accordingly since only one of these could be made to agree with the specimen temperature, test 14 was run with the current through the end heaters adjusted to make couple No. 1 agree with the specimen temperature of 610 deg. fahr. As can be seen from the curve for test 14 (Fig. 27), there was considerable drop in temperature along that part of the specimen holder within the main furnace from the specimen end toward the end of the main furnace, and the differential throughout the specimen was 12 deg. fahr. It was decided that it would be more desirable to have a more uniform temperature along those parts of the holders in the main furnace, and accordingly in test 15 (Fig. 27) the current through the end heaters was controlled to make the temperature at couple No. 9 agree with the specimen temperature, couple No. 7. The maximum temperature differential between the three couples inserted in the specimen was only 2 deg. fahr., while the maximum differential throughout the specimen and that part of the holders within the main furnace was only 15 deg. fahr.

Test 16, Fig. 27, was a repetition of test 15, but with a specimen temperature of 900 deg. fahr. The temperature differential throughout the specimen was 6 deg. fahr., and throughout the specimen and those parts of the holders within the main furnace was 42 deg. fahr.

One set of readings from each test referred to, taken after temperature equilibrium had been reached, is given in Table 3.

After careful consideration it was decided that the best method of operating the furnace would be to regulate the current through the end heaters to make couple 9 agree with couple 7, or since couple 7 could not be used when the specimen was being pulled, to make No. 9 agree with the average of the temperatures as measured by couples clamped to the top and bottom shoulder of the specimen.

A comparison of the temperatures as measured by couple No. 6 which was inserted in the top shoulder of the specimen and by couple No. 12 which was clamped to the top shoulder of the specimen, shows that the clamped-on couple can be relied upon to measure the temperature of the specimen. The addition of the end heaters and reconstruction of the main furnace reduced the temperature differential between the specimen and the surrounding air from 115 deg. fahr., to less than 20 deg. fahr. This condition would tend to make the clamped-on couples more reliable, since no part of the couple near the hot junction is exposed to a temperature very much greater or less than the temperature of the hot junction.

The results of tests 13, 15, and 16 indicate that for specimen temperatures as high as 925 deg. fahr. a temperature differential throughout the specimen not to exceed 6 deg. fahr. may be expected, and that the temperature of the top end of the specimen should not drop appreciably as it is being pulled, even when the specimen temperature is such as to produce large elongations.

During the actual pulling of specimens, only a relatively few couples can be used, and after due consideration it was decided to use one couple in each of the end heaters and the main furnace

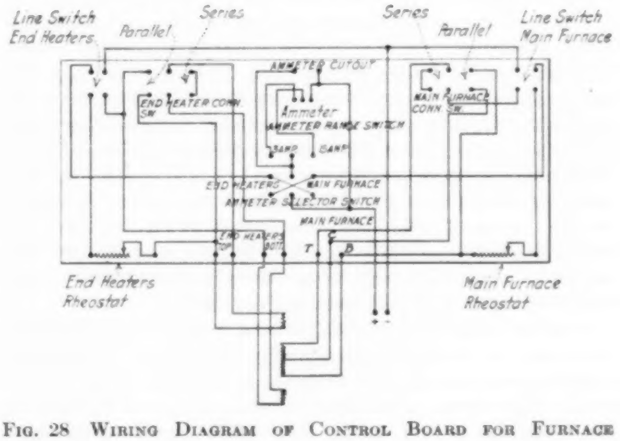


FIG. 28 WIRING DIAGRAM OF CONTROL BOARD FOR FURNACE

to measure the atmospheric temperatures. In addition to these furnace couples, a couple was inserted in the bottom holder in the same position as couple 9 in tests 13 to 16. Since the bottom holder did not have to be removed to insert or remove a specimen, a couple could be permanently mounted in the bottom holder without interfering with the operation of the equipment. Two couples to be clamped to the top and bottom shoulders of each specimen pulled were also provided.

The cold junctions of all six thermocouples were inserted in a thermos bottle, and all couples were connected to a sensitive indicating deflection-type pyrometer by means of a selector switch. In addition to the indicating pyrometer, a recording pyrometer was connected to the couple in the bottom holder and the two clamped-on couples; this not only provided a permanent record of the pertinent temperatures, but showed the trend of the temperature curves and enabled the operator to better adjust the rheostats.

During tests 14 to 16, a record was kept of the current required

through the main furnace and through the end heaters to produce the desired conditions at the several different temperatures, and from the data obtained, curves were drawn to show the current required in both circuits to maintain any desired specimen temperature. These curves, although not satisfactory for the final adjustment of the rheostats, enable the operator to adjust the rheostats approximately correctly without undue hunting.

The complete equipment, consisting of the furnace, control board, and pyrometric equipment, was set up and turned over to the laboratory with the following recommendations:

> After the specimen is mounted in the furnace, the temperature of the specimen should be brought to the desired temperature as closely and quickly as possible, and with as little hunting as possible. The temperature of the couple in the bottom holder should be made to agree with the temperature of the specimen to within ±3 deg. fahr. The specimen should be allowed to remain at temperature equilibrium for at least 20 minutes before the pull is started. Temperature equilibrium is defined as a rate of change in temperature of less than 2 deg. fahr. in 10 minutes or 12 deg. per hour. The temperature of the top and bottom shoulders of the specimen and the temperature of the bottom holder as shown by the indicating pyrometer at the beginning and end of the pull should be recorded.

The relatively fine-gage iron-constantan couples used in this equipment, the same as those used in the tests, are not satisfactory for long use, but the thermoelement wire is relatively inexpensive, even with the asbestos insulation, and it is a simple matter to make up new couples and install them.

The bureau staff believe that they are measuring the temperature of each specimen pulled with an accuracy of at least ±1.0 per cent, and that the maximum temperature differential throughout the specimen during routine tests does not exceed 10 deg. fahr.

The apparatus as described above was designed and used for the testing of aluminum and aluminum alloys which have a high coefficient of conductivity for heat. The high conductivity was undoubtedly of considerable advantage and instrumental in securing a low temperature differential throughout the specimen. Table 229 on page 213 of the Smithsonian Physical Tables, 7th revised edition, gives the coefficient of conductivity for aluminum at 18 deg. cent. as 0.514, and for 1 per cent carbon steel at 18 deg. cent. as 0.108. The bureau staff would not expect to obtain as good results with steel in this furnace as they do with aluminum, and considerable further alteration might be necessary to produce equitable results with steel specimens.

A similar investigation of all furnaces used for this purpose to determine the temperature uniformity throughout the specimen and the accuracy of measurement of specimen temperatures would do much to substantiate the data obtained by independent investigators and make their data much more comparable.

Acknowledgment is made to Mr. J. K. Miller, Jr., for his assistance in conducting the many preliminary and final tests of this apparatus.

## Discussion

J. M. Lessells.[10] The method described in this paper of measuring elastic extensions is novel, but experience indicates that it would not be suitable for materials like steel with higher modulus values. This of course has been realized by Mr. Templin, and he has made remarks accordingly. This point, however, is worthy of emphasis.

A further point of interest is in Fig. 6. The writer would suggest that the authors include the temperatures on the curves, because the curve for 200 deg. fahr. has not been shown.

[10] Engineer in Charge of Mechanics Section, Research Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa. Mem. A.S.M.E.

The "kink" in the tensile and yield-point curves for alloy 112 as cast and for alloys 195 and 196 as heat-treated are interesting. Mr. Templin comments on the fact that such phenomena have been observed by other investigators but have not been explained, yet he does not explain these peculiarities himself. It would be very interesting to have more comments on this phase of the work because it should be noted that the alloys giving these peculiarities are all high in copper. Possibly the phenomena are due to release of residual stresses, due to structural changes during the aging process, and one would expect great changes in the form of the tensile-test diagram after this aging. It should also be noted that alloy 122, also high in copper, does not show these peculiarities, therefore such cannot be due to copper alone.

With the fine furnace equipment used in these tests it is to be regretted that the results of duplicate tests were not given. Mention is made by the authors of the fact that this variation was ± 4 per cent, but it would have been interesting to see all the values plotted.

P. G. McVetty.[11] The authors of this paper are to be congratulated upon the manner in which they have developed the apparatus, conducted the tests, and presented the results. The writer was particularly impressed by the details of furnace design given by Mr. Marsh. The use of end heaters to reduce the temperature gradients within the furnace is undoubtedly an excellent method of securing a more uniform temperature in all parts of the test specimen.

We also have found that a thermocouple held firmly against the surface of the specimen gives fairly satisfactory results.[12]

Mr. Marsh has mentioned the fact that the high thermal conductivity of the aluminum alloys tested has helped to decrease the temperature differential throughout the specimen. This emphasizes a point which is often neglected, namely, that the same furnace is not equally satisfactory for all materials.

There is one other factor that the writer would like to mention and that is the part played by the low modulus of elasticity of aluminum alloys in making the results more consistent. This modulus is very low at the higher temperatures, and as a result the deformation for a given change in stress is large. On this account the changes in length due to temperature fluctuations become relatively unimportant. If the same apparatus which has been described were used in testing alloy steels of the type adapted to high-temperature service, it would be found desirable to hold the temperature during the test within even closer limits. We have found that the results are much more affected by temperature fluctuations during the test than they are by small temperature gradients within the specimen.

The writer agrees heartily with Mr. Marsh that a similar study of the furnaces used by different investigators would aid materially in explaining the discrepancies found in comparing results obtained by different laboratories.

O. W. Ellis.[13] The authors have called attention to the speed of testing, particularly in the case of those alloys which can be age-hardened. The test samples, according to the paper, were in all cases kept at the required testing temperature for 30 min., and were then stressed to the point of failure, the speed of testing being 0.107 in. per min. The writer would be interested to know if any tests were made in which the test sample was kept for a longer time than 30 min. at the testing temperature or in which

[11] Research Engrg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa. Mem. A.S.M.E.

[12] P. G. McVetty and N. L. Mochel, "Tensile Properties of Stainless and Other Alloys at Elevated Temperatures." Trans. A.S.S.T., vol. XI, p. 100 (1927).

[13] Research Dept. Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

the test sample was pulled at slower speeds. The following possibilities come to mind: (1) The complete precipitation of solute compounds during a longer period of time than 30 min. prior to test, or (2) the complete precipitation of such compounds during the actual testing operation; this, however, occupying a longer period of time than usual, owing to the use of a testing speed of less than 0.107 in. per min. The question arises, what would be the effect of such precipitation prior to or during the test on the test result? It seems likely that as a result of the complete precipitation of the solute constituents prior to or during test, certain of the kinks which characterize the curves of the heat-treated alloys would be completely ironed out.

Mr. Archer, of the Aluminum Company of America, while discussing with the writer the possibility of using certain aluminum alloys as bearing metals, referred to a fact which is of considerable interest in this discussion, i.e., that aluminum bearings tend to seize on steel shafts very readily. He offered as an explanation of this phenomenon the relatively high affinity of aluminum and iron, an affinity which is considerably greater than that of iron for either tin or lead. Recently a paper was presented at one of the meetings of the Royal Society (Proc. Roy. Soc., 1927, 115 (A), 472) in which the rapid rusting both of lubricated and unlubricated steel parts in firm and close contact and moving slightly relative to one another was discussed and explained. In this paper Tomlinson, the author, says:

"The most probable explanation of the effect which suggests itself is that it is a result of molecular cohesion. When two solids touch, the forces between the molecules or at least some of the molecules are sufficiently high to cause the molecule to be detached by a lateral movement. It seems certain that the force between two molecules which approach and recede normally is definitely smaller than the forces holding either molecule to the solid. Experiment E in which the relative motion is always exactly normal to both surfaces shows this, and all experience with ball bearings proves that the rusting effect does not occur with pure rolling. The nature of the bonds between the molecules appears to be such that the cohesive force of a visiting molecule is quite insufficient to pluck the molecule out normally, but is sufficient to detach it from the solid when applied tangentially. This suggests the view that the boundary molecules, by virtue of their unsymmetrical position, have a considerable degree of orientation, so that an external tangential force is able to disturb the initial equilibrium so much that individual molecules as distinct from finite particles can be wrenched away. To use a crude analogy, a tooth is more easily uprooted by a side pull than by a normal pull. The molecules so detached combine very quickly with oxygen molecules from the atmosphere."

Stress is here laid on the ready combination of the detached molecules of iron with the oxygen of the atmosphere. When contact is made, as in bearings, between steel and aluminum, which is of all the commoner metals that most readily oxidized, the formation of a large amount of aluminum oxide can, under certain conditions of service, readily occur. On the one hand is the fact that there exists a film of oxide on the metal to start with; on the other, the possibility that relative movement could increase the amount of this oxide in the manner hinted at by Tomlinson. The speaker therefore is of the opinion that the affinity of aluminum for iron per se cannot account for the ready seizure of the two metals as in bearings, but that the affinity of aluminum for oxygen must be considered as of equal importance in determining bearing failures in which aluminum alloys play a part. There is no reason, however, why these alloys should not sooner or later be used in this connection. We have to find out how to use them on the one hand and where to use them on the other.

F. M. Brauer.[14] Three or four months ago, the Ordnance Department found a metal that was light, yet with physical properties that would permit its use in mobile anti-aircraft mounts. After spending considerable time in investigations, analyzing numerous tests, and consulting engineers and other experts, a metal having specifications known as No. 195, heat treatment No. 4, was found, which with but a few modifications would be adaptable. Six per cent elongation, 13,000-lb. per sq. in. yield point with 28,000-lb. per sq. in. ultimate, was established. Further than that an order was placed for this metal to be used in very important components of gun carriages. It may appear singular that the department should introduce a metal of this kind and put it into a gun carriage; however, there was no hesitancy in so doing, and we are firmly convinced that not only these components, but that in the near future other parts, will be changed over from cast steel having a 30,000-lb. yield point and 70,000-lb. ultimate, to aluminum-alloy casting No. 195.

Not only are the specifications as to physical properties carefully checked, but also an actual test is made and each member subjected to a load equal to that which will produce a fiber stress of 80 per cent of the strength of the metal at the yield point.

A. W. France.[15] The writer would be interested to know if any experiments have been conducted on aluminum alloys for possible use as piston or packing rings at high temperatures where copper alloys and cast iron no longer serve satisfactorily.

[14] Watertown Arsenal, Watertown, Mass.

[15] President, France Packing Co., Philadelphia, Pa. Mem. A.S.M.E.

# Sheet Rolling

By LEON CAMMEN,[1] NEW YORK, N. Y.

*In this paper, after distinguishing between strip and sheet, and between hot and cold rolling, the author points out that mills are today rolling to surface specifications which would have been considered impossible five years ago, and that barring certain contingencies, stricter specifications may prevail in the near future. In the course of his treatment of the subject he describes the continuous process of sheet rolling, temperature and labor, roll life, engineering economies of the sheet-rolling business, rolling with heating between passes, sheet rolling in Germany, sheet and roughing mills of the future, the price problem, etc. In the author's opinion the economic side of the industry will have to be reorganized along lines which have proved successful throughout the entire American industry; and this will be in the direction of reduction of the number of plants and concentration of output in larger and better-equipped units capable of meeting the strenuous specifications of today in an economical manner and by those knowing enough about their costs to demand a fair price for their products.*

IT IS COMMON to speak of industries as if they were living beings. Thus, we hear of the birthday of an industry, its silver anniversary, and the like. The art of sheet rolling is said to have originated in England in 1728. This would give this art an age of over two hundred years. An analysis of its present development would give it a mentality of twelve years as applied to steel, and probably around eight or nine years as applied to copper and brass.

## Sheet and Strip

In the rolling of sheets several distinctions are made which it is well to understand from the beginning. In the first place, a distinction is made between sheet rolling as such and strip rolling. The difference lies in the fact that in sheet rolling proper pieces of comparatively small lengths are produced, not in excess of 20 ft. as a rule, and usually varying from 96 to 144 in. In strip rolling very long pieces, up to 2000 ft. or even longer, are produced. A further distinction which held good formerly was that strip was supposed to be rolled in comparatively limited widths and varied from what is known as flat wire, say, $^1/_4$ in. wide, up to about 24 in. in width. Sheet was rolled from that width up to 48 in. as a regular commercial product, and 64 in. as specialties. This distinction has been largely done away with by the recent development of so-called wide-strip rolling by which sheet is produced today in widths up to 42 in. and could be produced in greater widths if commercial requirements could justify the very large expenditure involved. Technically, therefore, the difference between strip and sheet in the matter of width may be considered to be completely done away with.

## "Hot" and "Cold" Rolling

The next distinction made is between hot and cold rolling. This is a very important distinction, which makes it all the more unfortunate that the terms are entirely misunderstood in the trade. As improperly used today, rolling at temperatures in excess of, say, 1000 deg. fahr., is described as hot rolling, while by cold rolling is understood rolling where the metal entering the rolls is at a temperature somewhere between 100 and 200 deg. fahr. This is, however, an entirely improper description, and, for example, C. B. Francis and J. M. Kemp ("Making, Shaping, and Treating of Steel," 4th edition, p. 959) show that all rolling below the critical point (1290 deg. fahr. for the usual low-carbon steel) is cold rolling. This not only follows from the definition of hot rolling but is shown by the result. Steel rolled above the critical temperature, as, for example, in rail manufacture, when finished is strong and lacks the brittle hardness induced by cold working. It can therefore be subjected to its usual service stresses, among them shock stresses, without annealing. On the other hand, the so-called hot-rolled sheet as it finally comes out of the rolls has the coarse, elongated-crystal structure and brittle hardness distinguishing cold-rolled products and cannot be used for shaping or drawing without a preliminary anneal.

## Surface Specifications

A further distinction must be made, and that is between sheet specified to show a good surface and sheet where only the drawing qualities, strength, or the like, have to be produced. In a way, as will be shown later, there is no reason why all sheet should not be rolled to a good, clean surface. Actually, however, the requirements of modern specifications for certain classes of goods as regards surface are so stringent that the most elaborate precautions have to be taken to produce the desired kind of surface. Suffice it to mention as an illustration that a case is known where sheet was disqualified as to surface conditions because the roller inadvertently dropped a bit of cigarette ash while the piece was going through the rolls. The modern methods of painting, particularly as applied to such products as steel furniture and automobile bodies, are also such as to bring out the slightest defect in surface conditions. The result of this is that mills are rolling today to surface specifications which would have been considered absolutely impossible only five years ago, and all indications are that, unless new methods of painting and japanning are discovered, even stricter specifications than prevail today will be insisted upon and most likely obtained by the large purchasers.

There is still another distinction, namely that between sheets on which the manufacturer makes profit and those on which he loses money. But this, like the matter of one's religion, is a subject which can be discussed only between the maker of the sheets and his stockholders.

## Conventional Sheet Rolling

In the rolling of ordinary sheets (i.e., not strip sheets) of plain carbon steel (which means between 0.06 and 0.12 per cent), the customary cycle of rolling is as follows: A sheet bar is selected such that the length is equal to or slightly in excess of the width of the finished sheet. The width is usually 8 in., although 12-in. bars are sometimes used. The thickness of sheet bar is such as to give the necessary weight of the sheet, and usually varies from about 0.75 to 1.25 in., although of course lighter and heavier sheet bars are used for specialties. The sheet bars are heated to the selected rolling temperature, which may vary from 1550 to 1750 deg. fahr., in what is known as a "pair" furnace, so called because the sheet bars are taken out of it in pairs. When the bars have reached the proper temperature, the control of which is in charge of the heater, a pair of them are taken out by an attendant and dragged over by tongs to the roughing mill. The roughing mill is attended by two men, the roller and catcher. The former grabs one of the bars by tongs and feeds it into the mill. The catcher, standing on the other side, catches the piece and lifts it to the top of the roll, with the result that it rolls back to the roller. In the meantime the roller passes the second

[1] Consulting Engineer.

Presented at the National Meeting of the A.S.M.E. Iron and Steel Division, Chicago, Ill., November 14 and 15, 1928.

bar of the pair into the mill, so that for a while pieces of hot metal travel one through the rolls from the roller to the catcher and another over the top roll from the catcher to the roller. All of this is done with great rapidity, which is necessary in order to get as much rough rolling done as possible before the pieces become too cold, and requires great skill as well as strength, muscular endurance, and ability to withstand conditions which would lead to pulmonary and blood circulatory diseases in any one but those physically qualified for this kind of work. A combination of all these qualifications, together with the desire to do heavy muscular work, is not common in American labor and has to be paid for accordingly. While therefore the roughing mill is a cheap and simple piece of apparatus showing a comparatively low consumption of that kind of power which can be expressed in terms of pounds of steam or kilowatts per hour, the process of rolling is anything but cheap. This comes, however, under the relation of man power to mechanical power in sheet rolling, and will be discussed more fully elsewhere.

Practice in sheet rolling is not uniform throughout the country. In some plants roughing is continued only as long as it can be done with the original heat of the sheet bar; in others, the semi-rough sheet is reheated and returned to the roughing mill. The

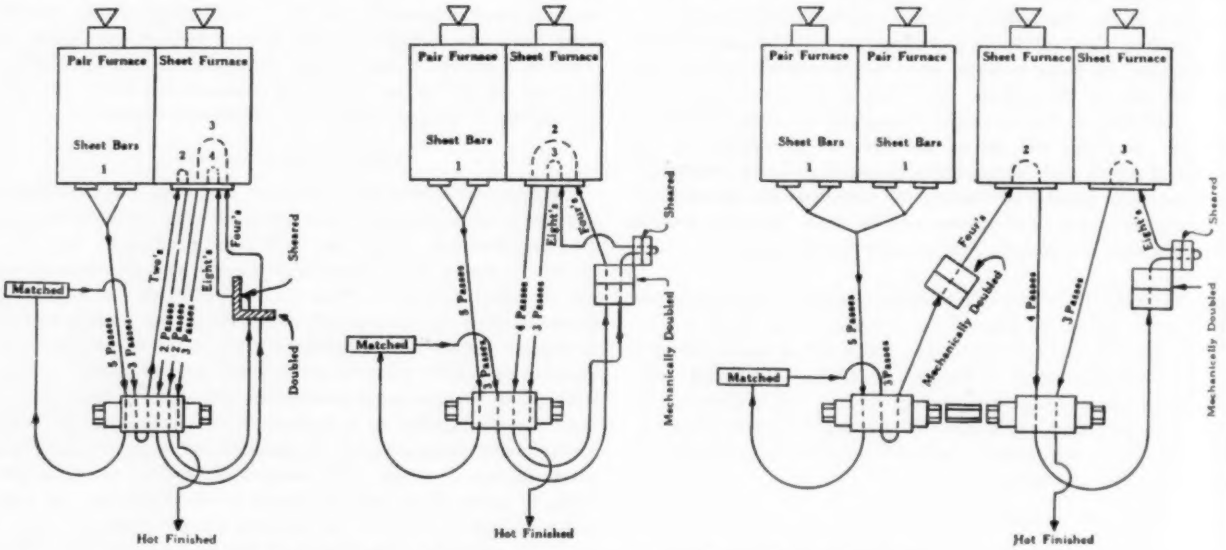


FIG. 1 THREE METHODS OF ROLLING BLACK PLATE FROM SHEET BARS

1 Various steps involved in rolling black plate from the heating of the pairs to the finishing of the pack as conducted by the majority of tinplate producers on a single mill by the four-part system. Thirteen distinct operations are entailed.
2 The installation of a mechanical doubling machine alleviates the laborious work associated with the folding operation and affords increased production by the elimination of one heating.
3 By doubling the equipment and operating two mills as a unit on the three-part system, larger tonnages can be handled than by working two mills singly on the four-part system and considerable backtracking is eliminated.

TABLE 1 CREWS REQUIRED UNDER VARIOUS SYSTEMS AND OPERATIONS ENTAILED IN ROLLING BLACK PLATE

| Single mill crew, four-part system | Single mill crew, three-part system |
|---|---|
| 1 Roller | 1 Roller |
| 2 Rougher | 2 Rougher |
| 3 Catcher | 3 Rougher's helper |
| 4 Catcher's helper | 4 Catcher |
| 5 Screw boy | 5 Catcher's helper |
| 6 Heater | 6 Screw boy |
| 7 Heater's helper | 7 Pair heater |
| 8 Doubler | 8 Pair heater |
| 9 Doubler's helper or pair heater | 9 Doubler operator |

Double mill crew, three-part system

| Roughing stand | Finishing stand |
|---|---|
| 1 Rougher | 9 Roller |
| 2 Rougher's helper | 10 Roller's helper |
| 3 Catcher | 11 Catcher |
| 4 Catcher's helper | 12 Catcher's helper |
| 5 Screw boy | 13 Screw hand |
| 6 Pair heater | 14 Heater |
| 7 Pair heater's helper | 15 Heater's first helper |
| 8 Doubler operater | 16 Heater's second helper |
| | 17 Heater's third helper |
| | 18 Doubler operator |

OPERATIONS IN ROLLING BLACK PLATE

| Single mill, our-part system | Single mill, four-part system | Double mill, three-part system |
|---|---|---|
| 1 Heating the bars | 1 Heating the bars | 1 Heating the bars |
| 2 Roughed (5 passes) | 2 Roughed (5 passes) | 2 Roughed (5 passes) |
| 3 Matched | 3 Matched | 3 Matched |
| 4 Rolled (3 passes) | 4 Rolled (3 passes) | 4 Rolled (3 passes) |
| 5 Reheated in twos | 5 Doubled | 5 Doubled |
| 6 Rolled (2 passes) | 6 Reheated in fours | 6 Reheated in fours |
| 7 Doubled | 7 Rolled (4 passes) | 7 Rolled (4 passes) |
| 8 Reheated in fours | 8 Doubled | 8 Doubled |
| 9 Rolled (2 passes) | 9 Sheared | 9 Sheared |
| 10 Doubled | 10 Reheated in eights | 10 Reheated in eights |
| 11 Sheared | 11 Finished (3 passes) | 11 Finished (3 passes) |
| 12 Reheated in eights | | |
| 13 Finished (3 passes) | | |

general tendency is to roll the sheet to about twice its desired thickness in the roughing mill. There is a limit to which sheet can be rolled singly. The permissible variation in thickness from standard gage is usually $\pm$ $2^1/_2$ per cent, which in the thinner gages amounts to only a couple of thousandths of an inch.

If it is considered that the expansion of the rolls may easily exceed this amount, it will become obvious why single sheets cannot be rolled to their final thickness, provided this is less than, say, 14 or 16 gage.

From the roughing mill the sheet goes to the doubler or matcher. The doubler is a device which folds the sheet in the same way as a piece of paper may be folded double. The introduction of the mechanical doubler some six or seven years ago was one of the most important advances in sheet-mill engineering and has produced a material savings in cost of operation. The usual method is to double the sheet and then put two or three of the doubled sheets together into a pack. The mechanical doubler is usually combined with a very simple device known as a mechanical matcher. The matched pack goes to the finishing mill where it may be rolled to the gage required. Two diagrams, Figs. 1 to 6 illustrate the various methods of rolling as determined by the use, or lack, of the mechanical doubler and by the use, or lack, of a separate sheet furnace as differing from the pair furnace, the former being then used only for the reheating of material rolled in the finishing mill, while the pair furnace retains its primary function of serving the roughing mill.

### Temperature and Labor in Sheet Rolling

A very significant light is thrown on the modern sheet industry by Table 1, which states the crews required under the various systems. The production in the United States varies from seven tons or less to fifteen tons per turn of 8 hours, or substantially around one ton per man in 8 hours. This saddles sheet making with a labor cost varying with various plants and various finishes and gage thicknesses but roughly of from $5.50 to $6 per ton of 22-gage sheets, which is more than ten times as high as is the case with any other rolled-steel product.

From the above certain significant conclusions can be drawn. In the first place, apart from the question of furnaces—which are becoming more and more expensive—sheet-rolling-mill equipment on the face of it is remarkably cheap. Where a rolling unit for any other product runs into seven figures, a sheet mill can be put up for less than $250,000. This is true, however, only if we accept the figures uncritically, because the sheet mill, unlike any other metal mills in American practice, has no mechanical manipulators and is operated throughout by manual power, although driven, of course, by mechanical power. To be fair, therefore, "first cost" of the rollers and catchers should be added to the cost of the sheet mill at the very least. The cost of a skilled workman in America is estimated at between $50,000 and $75,000, and the addition indicated will change completely the mill cost.

Moreover, American manufacturing conditions are such as to make the employment of manual labor basically uneconomical wherever it can be replaced by mechanical labor. Throughout the industry shovels, trucks, conveyors, manipulators, cranes, trench diggers, loggers, etc., have replaced man power. Bottles

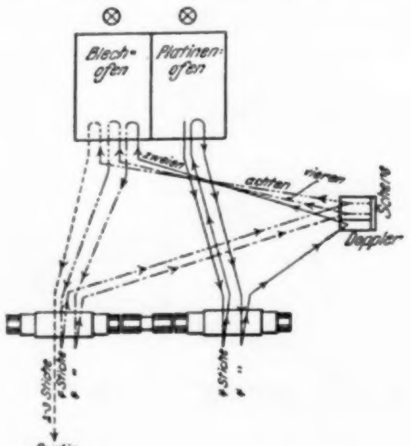


Fig. 2 German Double Mill for Old Five-Heat Process. Sheets 20.87 × 29.92 × 0.0079 In. Sheet Bars 9.84 × 0.472 In., Rolled Singly

(Sequence of operations: 1, heating the sheet bars; 2, roughing, 4 passes; 3, reheating; 4, rolling, 4 passes; 5, doubling; 6, reheating in pairs; 7, rolling, 4 passes; 8, doubling and cutting; 9, reheating in fours; 10, rolling, 4 passes; 11, doubling and cutting; 12, reheating in eights; 13, finishing, 3 passes. One pack of 8 sheets double length.)

are no longer blown by lung power, but are produced by the million by machinery. Cement sacks are also filled mechanically, and even in the sheet industry the automatic doubler and matcher has brought about a little revolution in methods of production. However, when it comes to rolling, exactly the same methods prevail as were introduced by the first Welsh mill men.

The use of muscular power instead of mechanical manipulators reflects on the industry in two ways: In the first place, the roller and catcher have to combine high-grade skill and judgment with a powerful physique, a combination by no means common, and therefore expensive.

In the second place, the roll speeds have to be proportioned not with regard to the best rolling conditions but with regard to the ability of the catcher and roller to handle the pieces. The standard speed for 28-in. rolls may be set at 30 r.p.m., which is entirely too low for economical production. Any

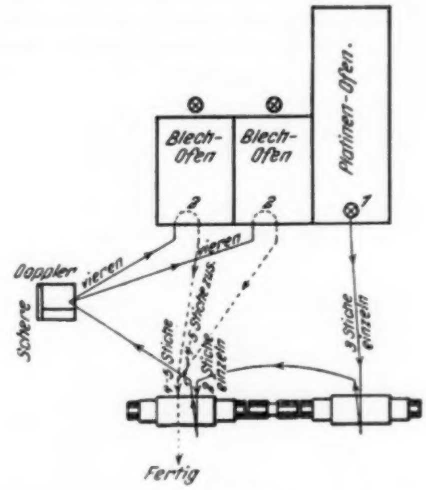


Fig. 3 German Double Mill for Two-Heat Process. Sheets 39.37 × 78.74 × 0.019 In. Sheet Bars 9.84 × 0.374 In., Rolled in Pairs

(Sequence of operations: 1, heating the sheet bars; 2, roughing, 3 passes each; 3, rolling on finishing stand, 2 passes each singly; 4, four or five passes sheets piled; 5, doubling and cutting; 6, reheating in fours; 7, finishing 4 or 5 passes. One pack of 4 sheets single length.)

higher speed of the rolls, however, would discharge the sheet with such energy as to make it difficult for the catcher to take it and would throw back the sheet to the roller at a speed that would make it dangerous for the latter. It is therefore the human factor and not mechanical considerations that governs rolling speed and hence mill output, and that is not a reasonable or desirable base upon which to plan operations today.

There is another angle to this question which also has to do with output. Because of the fact that sheet in rolling cools very rapidly the rolling is done in a tremendous rush, the roller and the catcher trying their best to reduce its thickness as much as possible before the sheet becomes too cold for further rolling. If we consider that a sheet bar may weigh from 75 to 125 lb. and the pack from two to three times as much, an idea will be gained of the exhausting character of handling such weights at topmost speed under conditions requiring strained attention and at a high surrounding temperature. The result is that probably not more than one-third of the time is actually devoted to rolling, and it may be added that it is a high testimony to the caliber of the men employed in sheet rolling that they can keep going at that rate day in and day out without breaking down or producing sloppy work.

### Roll Life

Now, what happens to the rolls while the men are resting? This is a question which has been seldom asked, not because it is difficult to answer, but because of the fact that the men have to rest has been accepted as a kind of natural condition along with weather, death, and taxes. When the rolls are working, heat is given up to them by the sheets. The temperature of the sheets may vary from about 1500 down to about 1100 deg. fahr. The temperature of the rolls is not supposed to go beyond 700 deg. and is preferably kept at about 600 deg. fahr. Now, when rolling is discontinued the rolls immediately began to lose heat by radia-

tion and conduction, which has two results. In the first place, since conduction losses and, in part, radiation losses occur more rapidly near the ends than in the middle, there is produced immediately a deformation in the shape of the rolls known as "bellying." Every sheet roller is gravely concerned over this factor, but does not generally realize that much of the trouble could be eliminated if the rolling were carried out at such a rate as to maintain a stationary condition of deformation rather than

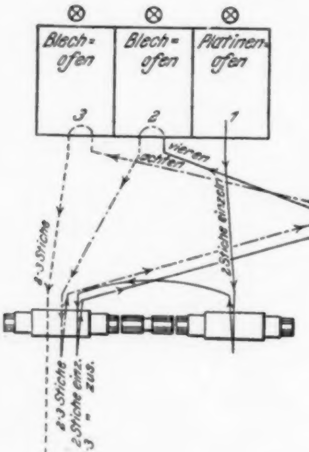


Fig. 4 German Double Mill for New Three-Heat Process. Tinplate 20.87 × 29.92 × 0.0126 In. From Sheet Bars 9.84 × 0.366 In., Rolled in Pairs

(Sequence of operations: 1, heating the sheet bars; 2, roughing, 2 passes; 3, rolling on finishing stand, 2 passes singly; 4, rolling together, 2 or 3 passes; 5, doubling; 6, reheating in fours; 7, rolling, 2 or 3 passes; 8, doubling and cutting; 9, reheating in eights; 10, finishing, 2 or 3 passes. One pack of 8 sheets double length.)

for the roll to swell out and approach again the cylindrical form many times during the turn.

In the next place it ought to be realized in this connection that a roll 30 in. in diameter and anywhere from 26 to 50 in. long contains a tremendous amount of metal. The cooling proceeds from the outside, while the inside is capable of maintaining its temperature for hours at a time. The result is that the inside retains its form and when the outside layer cools it produces a compression with respect to the inside mass and hence a tension in the outside layer itself. This condition is all the more dangerous in the case of hard rolls, as in addition to the contraction stresses produced in the outer layer, the difference in the coefficient of heat contraction between the hard layer and the soft core becomes operative. It is not difficult to realize what happens when the men cease recuperating and start rolling again. The outer layer, which is already in a state of strain, is suddenly subjected to a violent shock by the sheet going into the rolls. The results of this purely unreasonable condition show up prominently in the graph of the expense sheet called "roll maintenance," and most of the defacement of sheet surface is probably due also to the fact that small cracks may exist on the face of the roll for a long time before they become sufficiently prominent to warrant sending the roll back to the machine shop.

### More About Temperature and Labor

Because of the enormous cost of labor per ton in sheet rolling as compared with that of any other steel product, it is not surprising to find that the question of conservation of labor influences the entire structure of the art. The vital element of temperature of rolling is most closely affected thereby. In rolling rails, structural material, etc., an effort is made to carry on the operation through a comparatively narrow range of temperature and finish the rolling while the steel is still above the critical point, the result being that substantially the same grain structure is produced. In sheet rolling, however, it is economically impractical today to follow the same method. Rolling is therefore begun at a temperature several hundred degrees above the critical and carried on to one several hundred degrees below. As a consequence the material passes through the critical temperature at some time during the period of rolling, with the result that an uncertain conglomeration of crystal structures is produced and the material is weak and has to be annealed in order to impart to it the proper physical characteristics.

Furthermore, because of the desire to roll as much as possible between reheats, the initial temperature to which the metal is heated either in the pair furnace or in the sheet furnace is considerably higher than is actually required by the process of rolling. This tends to produce scale, and, where pack rolling is resorted to, to reduce the inner sheets more than is necessary as compared with the outer sheets.

There is yet another economical feature of the present method of sheet rolling which deserves close consideration and is a direct outcome of the fact that muscular labor and not mechanical devices actually control the art. It is significant and only natural economically that as the cost of initial equipment increases, the number of producers decreases and the prices become stabilized. The rail mill is probably the most expensive piece of machinery from the point of view of initial cost, and there are only three companies in the United States making heavy rails. Structural steels require somewhat less expensive equipment, and more companies are producing them. When we come to sheet rolling, we are striking approximately the same economic

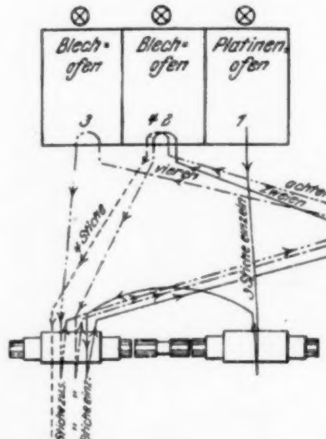


Fig. 5 German Double Mill for New Four-Heat Process. Sheets 20.87 × 29.92 × 0.0079 In. From Sheet Bars 9.84 × 0.472 In., Rolled in Pairs

(Sequence of operations: 1, heating the sheet bars; 2, roughing, 3 passes each; 3, rolling on finishing stand, 2 passes singly; 4, doubling each sheet separately; 5, reheating in pairs; 6, rolling, 4 or 5 passes; 7, doubling and cutting; 8, reheating in fours; 9, rolling 4 to 5 passes; 10, doubling and cutting; 11, reheating in eights; 12, finishing, 2 or 3 passes. One pack of eight sheets double length.)

situation as prevails in, say, ladies' dress manufacture. The initial investment of the plant is small, while the labor costs constitute the essential part of the total cost and do not vary much with the volume of production. It is because of this that in the dry-goods industry small establishments spring up all the time and to a large extent control the level of prices.

### Engineering Economics of the Sheet Business

In sheet rolling as constituted at present the costs for the same class of products are substantially the same in the smallest and the largest plant, while the investment required is so moderate that practically any experienced man with a little money can start making sheets. The small producers as a rule can work cheaper than the large ones, because the owner or the principal stockholders of a small mill are as a rule also its managers and consider the return on their investment largely in the way of salary, while the large mill is managed through hired executives and must make a salary return in addition to a return on stocks. Moreover, the small mill is hungry for business and often willing to work for a lower return. If we add to this that the small mill often does not know its own costs, it will become obvious why it can take away business from the big mill on a price basis and is apt to establish a general level of prices which would not be accepted in industries controlled by big units. It is because of this that except in a very few cases the sheet business has not contributed the share of profits that would be warranted by the volume of its output. In other words, the smaller sheet mills have been willing to do business on other bases than that of profits, and the big mills have had to follow the small mills because there was nothing else to do. It would appear from this that the economic salvation of the sheet industry lies in a complete reorganization of its method of production along such lines as have proved successful throughout the entire American industry, and this means adopting methods of production controlled by the following general principles:

*a* The workman must only control the manufacturing machinery and not operate it by muscular force.

*b* The consumption of labor per unit should be small and the consumption of power should compensate for the reduced consumption of labor.

*c* The first cost of the machinery may be high and the wages should be high, but the labor cost per unit of output should be low.

*d* The operation must be such as to provide automatically for the control of elements which are not of such a character as to require at all times personal control by the operator.

It is significant that throughout the steel industry these principles have been closely followed and have helped American industry in general to attain its dominant position in the world and produce, elsewhere than in the sheet industry, the comparatively large profits of the past ten years.

There have been only two branches of the industry which have not followed these principles but have relied on methods of the early part of the nineteenth century for their operation. These are the wrought-iron and the sheet-steel branches. The former, however, has seen the light within the last couple of years, and has passed from hand puddling to mechanical and chemical processes. There is every reason to believe that this change will produce substantial benefits for the wrought-iron industry. In the sheet industry likewise a more progressive spirit has appeared within the same period, and it remains only to see how helpful such steps as have been taken are likely to prove to the makers of sheet steel in the United States.

### Wide-Strip Rolling

The most expensive of the new developments has been the introduction of so-called continuous sheet rolling or, more correctly, the rolling of strip in sheet widths. The first attempt to do this proved to be a failure, partly because the economic conditions were not right and there was not enough business in given sizes to permit rolling continuously, and partly because the apparatus was not properly designed, and while it did turn out the product, there was so much trouble and such heavy maintenance costs as to make it impossible to compete with sheet made by more conventional methods. Within the last few years, however, a number of mills have been built which apparently are capable of rolling in an efficient manner, while the number of large orders for a few sizes has grown up to such a point as to make the economic operation of continuous mills feasible.

When the first continuous sheet mill was started at Butler, Pa., there was a very gloomy feeling, indeed, among the owners of non-continuous mills. While some of the claims as to the

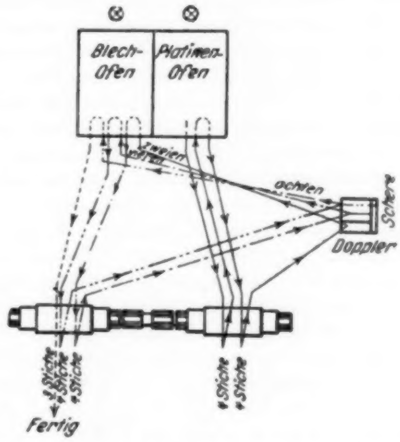


Fig. 6 German Double Mill for Five-Heat Process. Sheets 20.87 × 29.92 × 0.0126 In. From Sheet Bars 9.84 × 0.366 In., Rolled Singly

(Sequence of operations: 1, heating the sheet bars; 2, roughing, 4 passes; 3, reheating; 4, roughing, 4 passes; 5, doubling; 6, reheating in pairs; 7, rolling, 4 passes; 8, doubling and cutting; 9, reheating in fours; 10, rolling, 4 passes; 11, doubling and cutting; 12, reheating in eights; 13, finishing, 2–3 passes. One pack of 8 sheets single length.)

economic advantages of the continuous mills, such as that of saving $15 a ton on 22-gage sheets, were obviously wild, the sheet-mill owners were quite willing to admit among themselves that their plants might come to have only a scrap value within, say, two or three years. However, there is no such feeling today. On the contrary, the old-fashioned sheet-mill owner, or rather the owner of an old-fashioned sheet mill (these two are sometimes the same thing, but not often), is considering the situation quite cheerfully, and rather congratulating himself that he does not have a $5,000,000 or $7,000,000 mill on his hands and does not have to worry about paying fixed charges and facing possible revolutionary depreciations.

The fact is that at least in one respect the continuous sheet mill has failed, and that is in its ability to make sheets to sell at a profit. All that the continuous mill apparently can do economically is to produce breakdowns or material equivalent to that coming today from the roughing mill. Sheets have been rolled continuously to 18 gage. This requires, however, a considerable amount of coaxing and is not a general practice. Somewhat thicker sheets, such as 16-gage, can be produced with fair uniformity, but it is only at 14 and still better at 12 gage that the continuous mill shows up best. The wide-strip mill is therefore really doing only the work of the roughing mill, and the roughing mill in the non-continuous sheet mill of today is probably the most economical part of the equipment. The sheet bars are comparatively thick, hold their heat fairly well, and can be rolled easily and rapidly. They do not require as careful feeding as in pack rolling, and as a rule can be rolled down without reheating to the point where doubling or pack rolling comes in; and if they do need reheating they are cheaper and easier to handle than packs, because they are lighter and short, both of which make for cheaper handling. The continuous mill therefore really

leaves off at the point where the conventional finish rolling begins, and if the product of the continuous mill has to be finish-rolled in non-continuous mills, the saving is materially reduced, and when other factors are taken into consideration, it may vanish completely.

It should not be forgotten in this connection that the wide-strip mill of today is more or less a speculation. Its first cost is enormous and may vary from a couple of million to as high as ten million dollars. This means that the mill carries at 6 per cent an interest load which can vary from $120,000 a year to $600,000. But this is only the least of the fixed overhead charges, a much more important part being that of depreciation. Now, what should the depreciation on a wide-strip mill be? To answer this question it is only necessary to point out that the wide-strip mill is obviously a temporary expedient and can be considered as a permanent equipment only if and when a method of finishing is developed which will take the material from the wide-strip mill and convert it into salable sheets at a reasonable cost. Since no such method is as yet available and since it is the finishing of the sheet that constitutes the major part of the cost, it is entirely possible that a new method of operation will be developed which will render the wide-strip obsolete before it has had a chance to pay for itself. Such things have happened before.

The wide-strip mill has been a most interesting development and its mechanical success testifies to the very high status of mill engineering and to what can be done today when people make up their minds to do it and are willing to spend money. Certain problems which came up, however, are of considerable interest, one of the most important of them being how to control the movement of the sheet through consecutive pairs of rolls. The problem here differs materially from that encountered in conventional sheet rolling or conventional strip rolling. Mill engineers know that rolls have a tendency to lose their cylindrical shape and to be subject to what is known as "bellying," or an increase of diameter in the middle as compared with the ends. This can be remedied to a certain extent by making the rolls slightly concave, so that when the "bellying" takes place they will become truly cylindrical. Another method which has been suggested but not yet adopted to any conceivable extent is to machine the roll to a true cylindrical shape, operate it until it becomes hot, and while in that condition give it a further dressing which will bring it to cylindrical shape. Tools to do this are already available and it is merely a question of developing the necessary technique for doing the fine work required under rather unfavorable circumstances.

In conventional sheet rolling where the sheet bar or pack always travels through the same pair of rolls, a small amount of roll deformation not sufficient to affect the acceptance of the product is rather desirable, because it provides a guide for the sheet and makes it less likely for it to go crooked or shift sidewise. When, however, the sheet has to travel through a number of consecutive passes as in the strictly continuous mill or the cross-country mill, there is a possibility that the deformation of one pair of rolls may be out of line with that of another pair, with the result that the "guide effect" may be lost or may become a source of serious trouble. The American Rolling Mill Company at their Ashland plant sought to obviate this situation by deliberately controlling the deviation of the rolls from a true cylindrical shape and doing it in such a manner that the consecutive rolls would have gradually decreasing deviations from true cylindricity and be so arranged as to guide the sheet in a substantially straight line.

According to an editorial in *The Iron Age* of June 28, 1928, there are today two wide-strip-mill installations with a monthly capacity of 30,000 tons each, another one with 25,000 tons, one under construction with 30,000 tons, and two—one at Ashland and one in the St. Louis district—the capacity of which has not been officially given out but which may be estimated at 30,000 tons in one case and 20,000 tons a month in the other. This means an annual capacity of close to 2,000,000 tons a year, a tremendous amount to sell, particularly considering that the wide-strip mill is not economical except when it rolls fairly large quantities in one size.

### Rolling With Heating Between Passes

Another way to solve the problem of economic sheet production has been likewise initiated at the Ashland, Ky., plant of the American Rolling Mill Company. This installation deserves the most careful and sympathetic attention, because it embodies what appears to be a thoroughly sound principle. The only question is how economically the principle has been embodied in actual machinery. In this case the bar plates are sheared to lengths as they emerge from a holding furnace and are fed directly into a seven-stand jobbing mill which consists of four two-high 30-in. × 58-in. stands, and three three-high 30-in. and 14-in. × 58-in. stands. The product issuing from the jobbing mill varies in size according to the order being rolled, the length usually being about 10 ft., the width up to a maximum of 48 in., and the thickness ranging from $^1/_4$ in. down to 16 gage. The jobbing mill therefore corresponds to the roughing mill in the ordinary sheet mill. Following this the treatment given the roughed plates depends on the grade of sheets to be finished. Usually, the plates are matched in pairs, sheared on sides and ends, and

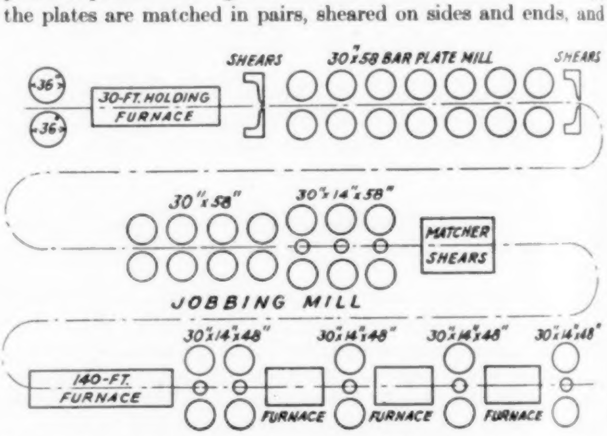


Fig. 7 Sheet Mill, American Rolling Mill Co., Ashland, Ky.

fed into a 140-ft. continuous heating furnace preceding the sheet mill. The mill consists of five stands of three-high 30-in. and 14-in. × 48-in. rolls, each stand being driven at about 25 r.p.m. Short reheating furnaces between stands 2 and 3, 3 and 4, and 4 and 5 maintain the material at the proper rolling temperature. Sheets of a maximum width of 41 in. and minimum thickness of 20 gage can be produced on this mill. Pairs of sheets are said to be finished at the rate of about 15 per minute. (T. J. Flaherty and A. F. Kenyon, in the *Electrical World*, July 21, 1928.)

The sheets after annealing and pickling are finished when necessary by cold rolling. The cold-rolling mill consists of eight trains of from 2 to 5 stands of 26-in. × 56-in. rolls. The usual practice is to give the sheets coming from the pickling machine about four cold-roll passes, then box anneal, and finally give a finish cold rolling of from one to four passes. The procedure varies, of course, according to the finish and temper required for the sheets.

The Ashland mill works on a correct principle in that the sheets in finish rolling are heated only sufficiently to carry them through stands 1 and 2. Reheating furnaces are provided between stands 2 and 3, 3 and 4, and 4 and 5, which means that heat must be added only to compensate for the loss in each pass; that is, the temperature of the metal can be maintained throughout

the rolling process within very close limits and the operation need not be controlled by the desire to save heat but can be carried out under the best physical and operating conditions without regard to the possible loss of heat that any delay may entail.

The only objection to this method is the very high initial cost thereof, which means that it is applicable only in mills which have a very large output. Considering, however, the enormous production of sheets in this country and the large market available, this is not a serious objection. On the contrary, should the Ashland method provide a satisfactory economy in operation, the high first cost might prove to be beneficial to the industry, in that it would concentrate production in comparatively few hands and make it possible to maintain in a legitimate manner prices that would give a reasonable profit to manufacturers of steel sheets. The other and more serious objection is that the process does not appear to be very flexible. This objection is stated with considerable hesitation, as the author is not fully familiar with the Ashland plant. It would appear, however, in view of the very large sizes of the furnaces, that variation of temperature would be quite difficult. Finally, there is a general objection to treating sheets, particularly those which have to be rolled to a fine finish, in any furnace heated by an open flame, which is based on two grounds. In the first place, no matter how carefully the temperature may be controlled, if any spot in the furnace is hotter than it is desired to have the sheet, the control is illusory. While it is true that a bright sheet does not absorb radiant heat well, there is no question that it can absorb in this way quite a large amount of heat. If the furnace roof or walls have a temperature higher than the sheet there is always a considerable amount of heat absorption which may easily be of local character, with the result that part of the sheet is heated to a greater extent than the rest. This remark is not made specifically with reference to the Ashland plant, but to all flame-fired furnaces.

The next objection to heating sheets between passes in open-flame furnaces has to do with the effect of this method on surface finish. Wherever there is an open flame there is spalling of the wall and roof of the furnace. The life of the bricks and lining in the furnace is limited. They are always breaking down, and this broken-down material has to go somewhere. As sheet is always present in the furnace, it is impossible to prevent a certain amount of furnace material from dropping on the sheet, and we all know what little things will spoil the surface of the sheet. Incidentally, furnace-wall material is not a trifling matter because of its abrasive nature and hence its ability to scratch the sheet and the rolls. Of course, the material being rolled can be protected to a certain extent by using what is known as a pilot sheet, i.e., an extra piece of metal to cover the sheet proper. This means, however, a not inconsiderable additional cost by way of material loss and extra handling, as well as a great increase in the duration and cost of heating.

## Surface-Combustion-Type Furnace

About a year ago a surface-combustion-type furnace was installed in the mill of a midwestern steel company for continuous normalizing of full-finish auto sheets. This furnace is about 102 ft. long with a 15-ft. preheat zone, a 45-ft. heating zone and a 34-ft. cooling zone. The fuel used is natural gas of about 1000 B.t.u. per cu. ft. heat content. The fuel consumption is said to be $1^1/_2$ cu. ft. per lb. The sheets annealed are 0.06 to 0.10 carbon steel from 16 to 22 gage and 48 in. wide in all lengths. The sheet enters the furnace at room temperature and leaves the heating zone at 1750 deg. fahr. It is held at 1500 deg. fahr. for a short time before final cooling to 1000 deg. fahr., the temperature at which the sheets leave the furnace. The temperature in each section is controlled without personal supervision or adjustment by three Leeds & Northrup automatic temperature-control instruments. The furnace is rated at $87^1/_2$ tons per 24 hr. with two men on the charging and two men on the discharging end. Special attention is called here to the output which is barely $3^1/_2$ tons per hr.

## Sheet Rolling in Germany

From time to time statements have appeared which have embodied certain wonderful claims in regard to performance in sheet rolling abroad, particularly in Germany. A careful study of the situation in the Reich would indicate that it does not differ much from that in America, and, if anything, things are not as far advanced there as here. W. Krämer, in an extensive series of articles published in *Stahl und Eisen* in 1927, begins by stating that "of the various rolling methods, that employed in the production of sheet steel is most unusual in that the skill and physical strength of the workman are still the controlling elements therein." That, of course, describes perfectly the American situation as well.

Methods of rolling are much less standardized in Germany than in America, and all kinds of combinations of roughing and finishing mills are employed. Among other things, the three-high mill is much more common in Germany than in this country. Table 2 gives substantially the German schedule of sheet rolling, while Tables 3 and 4 show the German outputs per mill and also incidentally give evidence that these outputs are lower than American outputs. At the same time it must be remembered that the German wages are less than one-third of the corresponding American wages. Fig. 2 shows diagrammatically the German layouts, which again do not materially differ from American layouts, except that the use of automatic doublers and matchers is somewhat less common in Germany than in America. The German industry incidentally works under the handicap that the production of the mills is very much lower than in America, which makes it less possible to put in improved machinery, should such be developed.

TABLE 2 GERMAN SCHEDULE OF SHEET ROLLING

| German gage | Thickness in mm. | Thickness in in. | Number of sheets in pack: Cold rolling | Number of sheets in pack: Hot rolling |
|---|---|---|---|---|
| 9–10 | 3.00–2.75 | 0.118–0.108 | Single | ... |
| 10–16 | 2.75–1.375 | 0.108–0.054 | 2 | Single |
| 17–20 | 1.25–0.875 | 0.0492–0.0344 | 4 | 2 |
| 21–22 | 0.75–0.625 | 0.0295–0.0246 | 12 | 4 |
| 22–25 | 0.625–0.438 | 0.0246–0.017 | 16 | 4–6 |
| 25–26 | 0.438–0.375 | 0.017–0.0147 | .. | 6–8 |

TABLE 3 OUTPUT OF GERMAN MILLS WHEN ROLLING HEAVY GAGES

(In metric tons per turn of 10 hours—see note below)

| Thickness in mm. | Thickness in in. | Three-high | Two-high, cold |
|---|---|---|---|
| 1.5 | 0.059 | 20–24 | 8–10 |
| 2.0 | 0.078 | 23–27 | 12–15 |
| 2.5 | 0.098 | 25–30 | 15–17 |
| 3.0 | 0.118 | 35–40 | 16–20 |

NOTE.—These figures apply to a layout comprising one roughing stand to one finishing stand, and efficient opration. The cold-rolling stand rolls run at 50 to 60 r.p.m., corresponding to a velocity of 1.8 to 2.1 meters (5.70 ft.) per sec.

TABLE 4 OUTPUT OF GERMAN MILLS OF LIGHT GAGES

(Finishing stand, in metric tons of turn of eight hours)

| Thickness, mm. | Thickness, in. | Output, tons |
|---|---|---|
| 0.5 | 0.0196 | 6.5–7 |
| 0.4 | 0.0157 | 6.0–6.5 |
| 0.32 | 0.0126 | 5.5–6 |
| 0.28 | 0.0110 | 4.5–5 |
| 0.22 | 0.0086 | 3.5–4 |
| 0.20 | 0.0078 | 3.3–3.8 |

## The Sheet Mill of the Future

It will be of interest now to look into the future, and in a general way to see what an ideal sheet mill may be expected to resemble.

Starting with the sheet bar, the 8-in. size is practically standard

today. It has, however, been adopted not because of its convenience in rolling but because its weight is such as to make it easy for the roller and catcher to handle, and particularly for the latter, as he has to elevate the bar by tongs to the level of the upper roll. There have already been objections made to this width of bar because it is not really economical, and furthermore, a longer bar would probably give a flatter sheet. Nevertheless, even the change to a 12-in. bar has been successfully resisted because of the greater difficulty of handling the heavier piece. Should mechanical means of handling be introduced, this objection would disappear, and in such an event there would be no reason why a 24-in. bar should not be used. This would cut in three the work at the bar shears, reduce, to some extent,

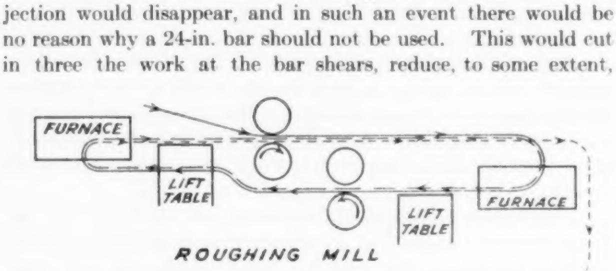


Fig. 8 Sheet Mill of the Future

waste on trimming sheet ends, and very materially increase the production of the roughing mill.

The next question is the temperature of the pair furnace. As a rule it is much too hot today. There is no reason why plain carbon steel should be heated above 1500 deg. fahr., a temperature which presumably is under the scaling point. This would permit pickling the bars before charging them into the pair furnace, which again would mean reduced cost of pickling, materially increased (in terms of tonnage of sheets) production of the pickling machine, and greatly decreased cost of the latter, because of the fact of handling shorter pieces than today. As reheating furnaces of a proper type will be provided in the future between passes, substantially as they are today at the Ashland plant of the American Rolling Mill Co., it will not be necessary to heat even the sheet bars to a temperature higher than required for the first two or three passes, and very likely the temperature ultimately selected will be much below the 1500 deg. fahr. mentioned above.

### The Roughing Mill of Tomorrow

Just what the roughing mill of the future will be it is difficult to say today; most likely several types will be employed. For a very large output the cross-country or tandem type of mill would naturally seem to be indicated, except for the fact that a constant distance would have to be maintained between the stands of the cross-country mill, while the length of the sheet varies. The result would be that in rolling shorter sheets there would be a certain loss of time and probably complications in the control of the heating furnaces to compensate for the increased lineal time that the sheet remains in the interstand furnace. This may, however, be accomplished by controlling the speed of travel of the sheet through the furnace, although these additional complications would not be welcome to the mill operator.

Where the cross-country mill is not acceptable either for the reason stated above or because of lack of space, or finally because the volume of production does not justify the comparatively large initial cost of such a mill, several other types are available. The three-high mill would probably be the first to be considered, as it is well known. With comparatively simple manipulating devices it can attain a very large production, and it is simple and cheap to operate. On the other hand, such a mill has one very grave disadvantage when it comes to rolling sheets, a disadvantage, however, which, as shown by German practice, is not too serious in the case of rough rolling.

This objection, or rather, difficulty, lies in the fact that, as stated previously, in sheet rolling both rolls are seldom truly cylindrical in shape. Roll treatment has developed to a point where it is more or less possible to maintain a pair of rolls in sufficient consonance of shape to permit good rolling, but in a three-high mill it becomes necessary to keep three rolls in a proper sequence of shapes.

The next mill that would come under consideration would be a "three-high" in which the middle roll is divided in two. A mill of that kind would consist of two two-high mills so arranged that the sheet going through mill No. 1 would make its exit above the top roll of mill No. 2, while the sheet going through mill No. 2 would pass below the bottom roll of mill No. 1. The two pairs would be always running in the same direction, but the direction of pair No. 1 would be opposite to that of pair No. 2. Proper tilting or lifting tables may be provided on both sides.

Finally, the present single two-high mill might be retained, but equipped with manipulators which would receive the sheet at one end, pass it over the top to the other end, and feed it into the mill again. The manipulator here would really do the work of the catcher. Of course, it would be quite easy to equip even the mill of today with such a manipulator, and there might be some advantage in doing it, but this advantage would not be very great because the rough-rolling part of the work is not the most expensive one. On the finish-rolling end such a device would not be advisable at all today, because with present methods of pack rolling and repeated reheating of the pack the saving through the use of a manipulator would not be large enough to justify the additional expenditure. On the other hand, if these manipulating devices were combined with reheating furnaces, then the pack would go through the mill and into the reheat furnace; from there the manipulator would take it back into the mill so that a pack could be completely finish-rolled without the need of dragging it to an outside furnace. With such an arrangement extremely rapid handling of the pack would become possible without imposing unreasonable strain on the men. Furthermore a very close control of temperature of the sheet could be maintained, assuming, of course, that the furnaces were of a suitable type. The speed of the rolls could be materially increased as the manipulators would be capable of taking the sheet from the mill at practically any speed at which the mill could deliver it. Calculation has shown that with such an arrangement the mill crew could be cut down to less than one-quarter of what it is today, the production of the mills could be doubled and perhaps tripled, costs could be materially reduced, and quality, especially surface quality, greatly improved.

### Great Changes in the Sheet Industry Inevitable

There is no doubt of one thing, and that is that the industry cannot continue in the way it is going on today. No industry in America can be efficiently carried on if it has to rely on labor which is at once highly skilled, willing, and capable of doing intense physical work. *The sheet industry cannot long continue to produce goods at the present costs and sell them at the present prices,* or at least at the costs and prices prevailing in the case of the majority of the producers. Changes in the industry are inevitable, especially in the direction of modified methods of production, which will unquestionably be based on the replacement of manual-

labor operation by manipulation by machinery, substantially as has already been done in all the other branches of the steel industry. The economic side of the industry will also have to be reorganized in the direction of reduction of the number of plants and concentration of output in larger and better-equipped units capable of meeting the strenuous specifications of today in an economical manner and knowing enough about their costs to demand a fair price for their products.

As a matter of fact, nothing radically new is here suggested. It is merely stated that the sheet industry cannot continue to be an exception in methods of production, as it is today, but will have to adopt the same principles of mechanization as have already been adopted by the remainder of the steel industry, and as are being adopted by other backward industries, such as bituminous-coal mining and agriculture. The Queen told Alice, of Wonderland fame, that in the Land Reached Through the Looking Glass "you have to be running as fast as you can in order to stay where you are." This is a true picture of modern industry. The sheet-steel industry has played the part of the Sleeping Princess for most of the time in its two hundred years of history—but industrial sleeping princesses are wakened from their slumbers, as a rule, by a splash of red ink.

Mechanically, changes will take place in the direction already clearly indicated by such mills as the Ashland plant of the American Rolling Mill Company, while the employment of a longer sheet-bar will make the operation of the wide-strip mill as a producer of sheet-mill breakdowns useful and possibly even profitable.

### Sheet Prices by Condescension

It might be well perhaps to touch on two matters in this connection. One is the talk going the rounds of the steel industry generally, and the sheet industry in particular, as to the necessity of educating the purchasers of steel products to pay higher prices for these products, thus eliminating what the sellers are pleased to call "ruthless" buying. This is the old story of the mice who met and decided that all cats should submit to having their teeth drawn. So far as history shows, this project has never succeeded. If buyers can buy cheaply, no association of sellers can induce them to pay more than the prevailing market price, and furthermore the buyers may, if they care to, remind the sellers of the time not many years ago when the boosting of prices by manufacturers was far more "ruthless" than is the depressing of prices by buyers today. It would be dangerous for engineers to rely on any such attempt to persuade purchasers to be superkind to sellers without a corresponding obligation by the latter to be good to purchasers should the tables be reversed, and of course no group of manufacturers can agree to any future maintenance of prices with the Federal laws governing this subject as they are today.

### Patents in the New Sheet Industry

Continuous sheet rolling, which is not a new art at all, but which has been developed to the commercial stage within only the last two years, is literally plastered with patents, particularly as regards details, accessories, handling apparatus, and the like. Unless the sheet-steel industry is alert, it will be worse off in the matter of patents than the radio industry is today, than which it would be difficult to find a more horrible example. The automobile industry has found a way out by what is known as the cross-licensing agreement, which, in its case, was possible because the most important technical developments were made within the industry, and because by the time the cross-licensing agreement was entered into by the automobile industry the main features of the automobile design had become common property, while the only serious patent threat, the Selden patent, has been smashed in the Ford litigation. Judging from the past, any development in the sheet industry will have to come from outside, so that a cross-licensing agreement patterned after that employed by the automobile industry would not be helpful here. Whether or not the Flat Steel Manufacturers' Association could be used as an instrument for acquiring patents affecting the entire industry and licensing all members, is a question which the industry itself will have to solve. To engineers, however, it would seem to be a highly wasteful and possibly dangerous situation by which they may be prevented from using important devices or be made to pay exorbitant licenses for the use thereof.

In the first paragraph of this paper the author ventured to state that while the industry is approaching the date of its second centennial, it is mentally only twelve years old. An industry which after two hundred years of existence is facing a complete reorganization and which in two hundred years has not evolved from the stage where it operates by brawn and sweat can be considered as being no more than twelve years of age mentally, particularly when compared with all other branches of the steel industry.

## Discussion

John W. Sheperdson.[2] Every product that is manufactured is governed in its price policy by supply and demand. Supply and demand together constitute competition. I do not agree with the author of the paper that the sheet-rolling industry is engaged in ruinous competition, or that it has a mentality equivalent to a boy 12 years old. On the contrary, I am convinced that the hot rolling of thin gages in wide widths has been and continues to be a problem to tax the wisest and most experienced rolling-mill men.

The problem of hot sheet rolling by the continuous method is much the same as the hot rolling of other small products by this method. Rods in large-weight bundles or narrow strips of thin gages and long lengths call for high delivery speeds to be able to produce them at all. High delivery speed spells high output, and high output spells ways and means of getting rid of the product to make room for the oncoming product. How can continuous rolling of any kind be justified unless it be done at a high rate of production? We all know what part the investment per ton of annual production plays in final costs; we simply must have a large divisor with a large investment.

Fundamentally, any method of manufacturing a product has its limitations. For instance, the Garrett type of rod mill is limited to a small rod bundle weighing around 180 lb. Any rod mill is ill adapted, except under unusual circumstances, to roll smaller than No. 5 rod. Beyond that point it is generally cheaper to cold-draw.

In the days of three-high sheet-bar mills, sheet bar was regarded the lightest section suitable for rolling on such mills, and could only be produced in short lengths from a small bloom or small ingot.

The continuous sheet-bar mill installed at the plant of the Youngstown Sheet and Tube Company some 23 years ago rolled this product for the first time from a whole 6500-lb. bloom direct from the ingot heat, and fitted into the scheme of the then prevailing, and for that matter now prevailing, system of sheet rolling.

The transition now in course of evolution in the production of sheets is to carry a semi-finished intermediate product down to lighter gages, at higher speeds, but up to the present no attempt has been made to do this from the initial heat of the ingot nor in weight of slab corresponding to the whole ingot. Therefore, reheating is a part of this new process.

[2] Chief Engineer, Morgan Construction Co., Worcester, Mass. Mem. A.S.M.E.

The difficulties are well recognized: speed, high tonnage per minute, and heavy torques mean power, and power beyond all previous concentration is being put into small rolls.

New metal in the rolls of sufficient endurance to withstand the localized pressures is required. These new rolls cannot come overnight. The American sheet-mill industry, far from showing temerity, has plunged into a new process pretty much regardless of cost, allured by potential advantages in sight. This is no twelve-year-old boy's job.

The problem before the sheet mills lies in finding if the old dividing line of economical production at sheet bar can be pushed forward and nearer to the finished sheet, or, stated another way, the problem is whether or not the cost of making some new semi-finished product, consisting of prime cost plus investment and carrying charges, can show a saving over the long-established practice of producing sheet bar at very low cost in a continuous mill, direct from the ingot heat, and then breaking down this sheet bar in hand roughing mills. Any figures I have been able to make do not point to net savings over the old method.

I do not think that the author has shown us conclusively how to build the next sheet plant, but he has brought to our attention the evils that now exist.

D. Eppelsheimer.[3] The author has sketched in a very interesting manner some of the features and possibilities of the recent development in continuous rolling of flat wide metal. The writer feels, however, that in discussing the economic importance of the new process of rolling, mention should be made of the developments in the finishing department which must be followed if full advantage is to be gained from the new continuous-rolling treatment.

It must be evident that new and advanced modes of pickling, annealing, cold rolling, and coating are of necessity employed in order to gain full benefit from the higher production of the continuous rolling.

The author has well stated one of the objects of the new process of the American Rolling Mill Company in its plant at Ashland. The writer might add, to avoid a misconception of his meaning, that the control of the shape of the rolls in successive stands of a tandem or continuous mill involves much more than the original turning of the rolls and heating of them by the piece. The shape between the rolls when the piece is being engaged is the critical thing, and it must be appreciated that this is affected by a number of factors ranging all the way from the rigidity of the mill housings to the character of the lubrication of the roll necks or bearings.

There are a number of problems other than those mentioned in the paper which required solution in order to substitute mechanical operation for the high degree of skill required by the hand rollers of the past. A discussion of these points is probably out of place before this group, which are not directly interested in the technique of sheet rolling, but it is believed that a full understanding of them would convince the members of the Society that the author has underestimated the difficulty of replacing the particular manual operations involved by a series of mechanical devices.

As stated in the paper, in the Ashland process the shape of the rolls when in engagement with the piece is deformed from the truly cylindrical, and the shape in each stand is less deformed than in the preceding one. This process of rolling wide, thin metal is used not only at Ashland, but at Butler and Middletown and by licensees of the American Rolling Mill Company at Weirton, and will be used shortly at Wheeling, and undoubtedly has a much wider application than the author apprehends.

Those members of the Society who visited Ashland will recall that the continuous pack-rolling units of the mill installation are planned so as to operate in parallel with each other, as well as in series with the continuous roughing mill, and it may be added that our experience indicates that it is fully practicable to provide continuous or tandem finishing mills, operating always according to the deformation process noted by the writer, for reducing sheet metal to any desired gage with large attendant economies.

With regard to the patent situation, it may suffice to say that the process referred to by the author of the paper as the Ashland process and discussed above has been recognized as patentable not only in this country but in many foreign countries.

The writer has had personal connection with the development of the patent situation of the American Rolling Mills Company, and has attempted to keep informed on the patent situation in general. To his mind there is no basis for a fear that rival concerns are on the way to, or are even unconsciously drifting into, the position of interfering with each other by means of trivial patents. The entire situation was, as he believes, so completely worked out by the American Rolling Mill Company before the industry became convinced of the practical importance thereof, that there is but little room so far as this development is concerned for the automobile or radio situation to be repeated.

R. J. Wean.[4] The author is to be commended on the frankness with which he has confronted the sheet industry with what he considers their shortcomings. In this brief discussion it may therefore be well to give due credit to the accomplishments of those engaged in this great industry, whose total output this year will approach five million tons, having an approximate sales value of from \$300,000,000 to \$400,000,000.

When it is realized that the sheet and tin plate industry has invested upward of \$75,000,000 in the last two years for the production of tinplate and sheets by new methods and processes, they cannot, in all fairness, be accused of a total lack of progressiveness.

While it is true that for many years the industry was slow to take up new developments, it must be remembered that this was during a period when profits were ample to satisfy the stockholders and the pressure of low selling prices was not present. In recent years the industry has made tremendous strides in the improvement of the quality of its product, and has also greatly increased production from existing equipment.

For many years the sheet industry was largely in the hands of mill men—men who had been trained to roll steel by actual experience. Very little engineering knowledge was applied to the industry as a whole, and this possibly accounts in some measure for the lack of progress, as in recent years the developments that have taken place in the sheet industry have been brought about by applying engineering effort. This has been done, in most cases, by the companies producing sheets, rather than by those outside of the industry.

As was stated by the author, probably the greatest development in the industry has been that of rolling wide-strip steel. The product from these mills is already being used in a wide market.

Strange as it may seem, the introduction and development of wide-strip rolling when used for tin-mill breakdown purposes caused the development of new methods of heating, as well as new methods of finishing this material, that can be applied to

[3] American Rolling Mill Co., Middletown, Ohio.

[4] Vice-President, Aetna-Standard Engineering Co., Youngstown, Ohio.

any existing conventional-type sheet or tin mill. Continuous pack-heating furnaces and mechanical catchers for the mills constitute largely these improvements at the present time, and this permits an increased output per mill with a reduced mill crew.

These developments are available to all producers under license, and some producers have already taken advantage of this in both the sheet and tin-plate industries.

In past years on full-finished or automobile sheets it was general practice for the bars to be roughed down from two to four passes on the roughing mill and then swung to the finishing mill where they would be given several additional roughing passes before matching. The pack would then be returned to a sheet furnace for reheating, and subsequently finished on the finishing mill.

When operating in this manner, one crew would operate both the roughing and finishing stands. The result would be that either one of the mills would be idle 30 to 40 per cent of the time, and in many cases even more. During the past year what is known as the "double-mill" or "Tipperary" system has come into quite prominent use, the roughing mills being operated by one crew and the finishing mills by another, so that all mills are operated as nearly 100 per cent of the time as heating and mill conditions will permit.

Many sheet producers thought that this would not be practicable, but it has been proved within the last year that it is not only practicable but highly desirable; and this system will lend itself very favorably to the installation of continuous heating furnaces and mechanical appliances not only to cut down the labor required but also to step up production. To the writer's knowledge as much as 25 to 30 tons of 19-gage sheets 36 in. wide, and 78 in. long, rolled three in a pack, were finished on a sheet mill of the above type in eight hours. When this is compared with the old-style production of 9 to 12 tons in eight hours, it can readily be appreciated what this will mean to the sheet producer in the form of reduced cost, as well as increased tonnage, without the addition of any actual rolling equipment.

When all of the economies of this nature have been accomplished in what we shall term the "conventional-type" sheet mill, it will be extremely difficult for wide-strip-steel producers to manufacture at a lower cost than the ordinary sheet-mill producers.

It was stated in the paper that the cost of a sheet mill was \$25,000.[5] Lest there be some misunderstanding, it may be well to clarify this to some extent. This represents—and the writer thinks it is low—the cost of a hot-mill stand, but does not include any other plant equipment. The actual cost today for erecting an 8-stand sheet mill would run from \$1,500,000 to \$2,000,000, or about \$250,000 per hot mill. This of course would include buildings, furnaces, and other machinery, without which it would be impossible to operate the mill.

The foregoing facts and the completion of present developments will probably demonstrate that the sheet industry is very much alive to its problem and well on the way to at least a partial solution.

Lloyd Jones.[6] When the writer recalls to mind the various specifications as to gage, surface conditions, and physical properties required of the modern sheet maker, he is inclined to believe that that individual is entitled to a mentality rating far in excess of the one given in the paper.

In regard to the distinction between sheets and strips, there need be no confusion in the steel industry. Sheet-mill and strip-mill practices are radically different, as any one familiar with the art knows. The fact that sheet manufacturers will slit sheets into strips and the fact that the strip manufacturers will cut strips into sheets has nothing to do with the fundamental differences between the two processes of manufacture.

Sheet practice over a long term of years gradually developed into widths up to 64 in. The strip process over a period of years has steadily been increasing in widths, and the fact that the range has recently been increased up to 42 in. is a logical development and not a new and startling innovation as many would have us believe.

The author has ably covered sheet-rolling practice, but the writer cannot agree that the wide-strip mills have proved a failure. Of the last three wide-strip mills to be put in operation, two exceed expectations in thinness of gage and the third is producing within the limits of gage for which it was designed.

It is true that under the present hot-strip practice 12 to 16 gage may be considered commercial limits in wide widths, but with the addition of cold rolling these strips can be reduced to any gage desired. The writer cannot see anything fundamentally wrong with the strip process and believes that it is merely a question of time until these latest mills will be operating satisfactorily.

In his further treatment of the wide-strip mill, the author overemphasizes the difficulty of controlling the movement of a single continuous strip through successive stands of rolls. The strip-rolling process, both hot and cold, has been practiced for quite a few decades and the writer has not yet been converted to the idea that the control of the strip going through the mill has been only recently accomplished, by means that are new and novel.

The writer does not believe that the Ashland plant of the American Rolling Mill Company will be duplicated, and is of the opinion that future developments will instead follow along the lines of the old-established hot- and cold-rolled strip process.

The writer's vision of the sheet mill of the future is radically different from that set forth in the paper. The mill, as he views it, disregarding the raw-material manufacturing end, such as blast furnaces, open hearths, slabbing mills, etc., and starting from slabs of required widths and in thickness ranging from 2 to 3 in., would first consist of a modern wide hot-strip mill divided into two sections, a tandem roughing section and a continuous finishing section. The product of this mill might range from 12 to 36 or 42 in. in width, as desired. In thickness, covering the entire width range, the mill should be capable of rolling in lengths, say, about 250 ft. long, gages ranging from 3 (max.) to 26 (min.). By this he means hot-rolled strip 36 or 42 in. wide, and 26 gage thick. With such a range of widths and gages, the mill would cover jobbing-mill plates and sheets within the width capacity in all gages, sheet-mill products within the width capacity, and ball gages down to 26 gage—probably 75 per cent of the sheet tonnage.

As to tin-mill products, the mill would cover 18- to 22-gage material, which could be doubled and hot rolled on a hand mill to light gages. An alternative to this would be cold rolling on cluster or backed-up mills to the desired gage.

Besides covering 75 per cent of the common sheet tonnage, the mill would produce suitable gages covering the entire cold-rolled strip industry and the full-finished sheet industry within the width capacity of the mill, namely, 36 or 42 in. wide.

It should be noted that with the proper equipment of the blue annealing furnaces, cold-rolling mill, tin and galvanizing pots, etc., the installation will no longer be a single-purpose one, but a layout covering a wide range of products, flexible in character and one which, the writer believes, will be more economical in operation than our present-day plants.

It sometimes requires a great deal of courage for an engineer to predict the future, but the writer bases this picture on his knowledge of the present hot- and cold-rolling industry and also

[5] This of course should have been \$250,000, as in the original manuscript. The mimeographed paper distributed at the meeting contained the misprint of "\$25,000."—Author.

[6] E. W. Bliss & Co., Salem, Ohio.

on the fact that hot strips of long length 24-gage thick have been produced from a hot slab in one rolling without reheating by a new process recently developed.

In closing the author cautions the sheet industry not to become involved in a patent situation similar to that existing in the radio industry. Personally, the writer does not believe the sheet industry needs fear such a condition, because the sheet industry is 200 years old and the strip industry probably 60 years old, while the radio industry is the product of the last few years. If attorneys and inventors will familiarize themselves with the art, not only as it exists in the patent office but as it has been and is practiced, no confusion need arise.

H. L. Bodwell.[7] While the author's statements as to the apparently slow progress made in the rolling of sheet steel mechanically or semi-automatically, as compared to that made in other lines of steel products, are no doubt true to a considerable extent, the writer cannot refrain from taking some exception to the indictment that the mentality of the business is but twelve years of age.

Producers of sheet steel have, for a great many years, been alive to the desirability of some form of continuous rolling with the consequent elimination of at least a part of the expensive and laborious hand labor incident to the present practice, and great amounts of thought, effort, and money have been expended on the problem in the way of experimentation.

The difficulties heretofore have been largely of an engineering nature, due to the lack of mechanical devices not yet invented, or the lack of knowledge or experience in the behavior of the material being handled under the different conditions to which it is subjected in the process. It is peculiarly fitting, then, that such a paper should be read before a body of mechanical engineers, such as this. The field for the application of inventive genius is unlimited. The continuous or semi-continuous process of rolling from ingot or slab, on the initial heat or with some intermediate continuous heating, to the finished sheet or "broad strip" has already reached a highly satisfactory degree of development in so far as heavy gages are concerned.

The general plans and details of operation and construction of these continuous mills have been fully covered in various papers read before societies or published in the trade journals. No further description is necessary at this time. As mentioned in the paper, there are continuous mills in existence today capable of rolling 50 to 60 gross tons per hour into strips of 14 gage or heavier, up to 48 in. wide and into 16-gage or 18-gage up to 32 in. wide, at a saving in labor as compared to the similar roughing operation on old-style mills of $5 to $6 per ton.

The further reduction of the hot-rolled product to lighter gages, such as 22 or even 24 gage, is also accomplished successfully by means of continuous 4-high cold-roll mills. The product from such a mill is available for sale as ordinary black or blue annealed in jobbing-mill gages, up to 48 in. wide, and by further reductions and combinations of treatments, such as pickling, cold rolling, annealing, or normalizing, for sale in 20 or 22 gages, of limited widths and whatever grade as to finish or drawing qualities may be desired.

Such a mill can also act as a feeder for the old style of finishing mill, either in so-called bar plate cut to the proper width to furnish the weight necessary for the gage and size of sheet to be rolled in such thickness as to do away with the present old-style roughing mill, or by furnishing sheets already roughed to receive whatever further treatment is necessary on the old-style finishing mill to obtain any grade or gage desired, thus doing away entirely with the roughing operation and thereby increasing the capacity of the finishing mill.

The successful operation of a continuous mill of the type in question is manifestly a large-tonnage proposition and can only be carried on economically when the quantity and character of orders are sufficient to keep it in continuous operation. The limitations in gage and widths existent with the present forms of continuous mills will no doubt be gradually raised as experience is gained and mechanical and electrical devices are perfected for more accurate control of screw pressure, roll temperature, and speeds.

The problem of hot-rolling sheet widths continuously from slab or bar, with or without intermediate heating, into light gages, such as 24 gage and lighter, is vastly more difficult of solution.

A brief description of the present method of rolling light-gage sheets will possibly assist in the visualization of some of the difficulties involved.

While the fundamentals in the method of rolling light-gage sheet iron remain about as they were when the industry was first introduced into this country from Wales early in the Nineteenth Century, there have actually been many developments made tending to improve the quality and quantity produced per unit and to reduce the laboriousness of the work as well as better the working conditions.

The rolls have increased from 18 or 20 in. in diameter to 30 or 32 in., with corresponding increases in the size and strength of the housings and drives. Methods of heat control of the rolls have been perfected so that variations in temperatures are held within 50 deg. fahr. in all stages of the rolling operation, with consequent longer life of rolls. Roll breakage is now a rare occurrence, and it is usual to obtain a life of roll of 100 days or more before it has to be discarded on account of the removal of the entire chill.

Preheating of rolls is practiced, eliminating the necessity for making a large amount of more or less unsalable warming-up sizes, and permitting the immediate rolling of orders, with consequent better deliveries.

Continuous pair furnaces are used, with less labor in charging and elimination of puddling, and with improved quality of pair heating. Mechanical doublers have been introduced, doing away with one of the most difficult jobs. Various mechanical means of handling bars and packs into sheet furnaces and at mills have been devised. Working conditions have been improved by the installation of water-cooled floors, ventilating systems, and forced-air cooling systems. On the whole, many improvements have been made and the output per mill has been doubled during the last twenty-five years.

The rolling of sheets has remained to this day a process requiring a great deal of skill and close supervision on the part of the rollers, combined with considerable laborious work performed in comparatively difficult surroundings.

The standard mill unit consists of a roughing mill, sometimes called the "soft" mill, with both top and bottom rolls driven; a finishing mill with only the bottom roll driven, the top roll being driven by friction; and the necessary complement of pair and sheet furnaces, shears, doublers, etc.

The roughing rolls may be of steel or gray iron, but usually worn-out finishing rolls are utilized. They are kept cold by means of a spray of water. The finishing rolls are of cast iron, with about $^3/_4$ in. of chill, 28, 30, or 32 in. in diameter, of a length suitable for the ranges in widths to be rolled, varying from 34 in. in length of barrel to 84 in., and weighing from 8000 to 25,000 lb. They are run hot, but kept below about 750 deg. fahr. by means of steam or air blower. The crew consists of the roller, who is the foreman of the crew and has general charge of

[7] Assistant District Manager, American Sheet & Tin Plate Co., Vandergrift, Pa.

all operations on his mill, and a sheet heater, roller's helper, heater's helper, rougher catcher, pair heater, pair-heater's helper, matcher, doubler, shearman, leader, and opener. Additional help is provided as required because of excessive weight of bars or for other reasons.

The bars are drawn from the pair furnace in pairs and broken down on the soft mill until approximately $^1/_4$ in. thick, then are swung over to the finishing mill where the roughing is finished, the rougher and catcher doing this work. The two pieces are matched together at a convenient length and thickness, and the roughing finished in that way.

After the roughing, the breakdowns are matched or doubled, and reheated in the sheet furnace. After reheating, if 28 or 30 gage, 72 to 84 in. long, the pack is run over on the finishing mill one pass, then opened, matched, and doubled again. The pack now consists of eight sheets and is reheated again in the sheet furnace and finished by the roller in as many passes as necessary to obtain the required length. Twenty-six gage is matched in threes after roughing and doubled into packs of six, then reheated and finished. Other gages are rolled either single or doubled in twos, threes, fours, as may best suit the particular gage and size being rolled. The bars are generally worked in heats of twelve pairs each. Both bars and packs are, at some stage of the process, worked below the critical temperature.

The different parts of the process are carried on by different members of the crew, each man having his designated duties to perform. As the greater part of the roughing, the run-over, and the finishing are done on the one finishing mill, those members of the crew performing each part have ample time to rest.

The hot-finishing rolls are kept almost constantly in use, and are therefore kept at a uniform temperature.

The duties of the various members of the crew are pretty well implied by the names given to them.

The pair heating must be carefully done in as nearly a reducing atmosphere as possible, and overheating and scaling avoided so as to save trouble later from open surface and pair-furnace scale or dirt. The rougher must rough straight and uniform to length so that the matching can be done properly. The matcher and doubler must match square on sides and ends, and double so the ends will be even in order to save head scrap and secure uniformity of gage and weight of sheet. The sheet heater must see that the packs are heated thoroughly and evenly in a reducing atmosphere and not overheated so as to avoid finishing scale, open surface, and non-uniformity to gage.

The roller, when finishing off the heat, must see to it that the condition and shape of his mill are correct for the material he is finishing. To this end he must see that the roll temperature is right and also the temperature of the necks, as variations in either will produce poor work. The surface of the rolls must be kept smooth by frequent polishing to avoid pitting or marking of the pack surface. The pack must be opened up, if necessary, before it is entered, in order to avoid patching and jumping.

Proper screw pressure must be given to avoid twisting, squeezing, flopping, or sticking, and the roller must watch the draw to avoid excessive length which will result in scrap loss and lightness of gage.

It will be seen that close, skilful supervision is required over all stages of the process in order to avoid the damaging effect of any irregularities, and that light-gage sheets are peculiarly susceptible to damage from a great many causes.

In the case of continuous rolling it would be all the more necessary to guard against any damaging effects, as corrections would be more difficult and a large amount of material might be ruined in a short time.

Whether the development of the continuous process of rolling the lighter gages in commercial sheet widths follows the present idea of the broad-strip mill or the continuous reduction of packs through successive passes, it is obvious that even more refined methods of adjustment and control will have to be devised than are sufficient in the mill for rolling heavier material. Not only will pressure of screws, temperatures of rolls and roll necks, or consequent shape of rolls need to be under absolute automatic control, but it will be necessary to maintain a uniform degree of heat in the material being rolled by some form of non-oxidizing application of heat between the successive passes. It will also be necessary to be able to change quickly from one gage and size to another.

These difficulties all seem of great importance and very difficult to overcome to those who are familiar with the sheet-rolling industry, but there is no doubt that they will all be surmounted if a sufficiently insistent demand arises.

Lane Johnson.[8] The author's statement that "at least in one respect the continuous sheet mill has failed, and that is in its ability to make sheets to sell at a profit," deserves careful consideration.

At this time, there are operating in the United States six wide-strip mills: The Ashland, Butler, Trumbull, Weirton, Gary, and Middletown. Ashland, Butler, and Middletown are owned by the same company and the other three by individual companies. At least three of these mills are producing full-finished sheets of 22 gage by strictly continuous hot and cold rolling. The fact that five of these six mills are operating now and have operated for a long time on schedules which approach the capacities of the mills indicates that the author's statement about profits is subject to a reasonable doubt. The sixth mill in the list has been in operation about two months and is being brought steadily into high production. The four companies which own these mills are large, well managed, and are accustomed to making profits.

The author, however, brings out one important point. It is the fashion in America to do things mechanically rather than by hand. Beyond question the continuous wide-strip mill does reduce the amount of hand labor required to roll flat steel, whether it be plates, strips, sheets, or tinplate.

### Author's Closure

My innocent remark to the effect that the mental age of steel sheet rolling is only about twelve years seems to have displeased practically every one of the discussers, and yet, nearly every one quotes facts which support my contention. John W. Sheperdson says that the American sheet-mill industry has plunged into a new process pretty much regardless of cost allured by potential advantages in sight. Plunging into something to the tune of about seventy-five million dollars "regardless of cost" under an allure shows the mentality of a green boy and not the mature mind of a full-grown man. Such temerity might be excusable if successful, but Mr. Sheperdson himself points out that any figures that he has been able to make do not point to net savings over the old method.

R. J. Wean acknowledges that very little engineering knowledge was applied to the industry as a whole, and sees in this the reason for its lack of progress. H. L. Bodwell goes still further and quotes lack of knowledge or experience in the behavior of the material being handled in sheet mills. What can one say about the mentality of an industry which has been in existence for two hundred years and does not know yet enough about the properties of the materials from which it makes a living?

The next statement in my paper to which objection is made

[8] Chief Engineer, United Engineering & Foundry Co., Pittsburgh, Pa.

is that the wide-strip rolling failed in at least one respect, and that is, ability to make profits. In this connection, attention may be called to the statement by Mr. Sheperdson already quoted above, namely, that his figures do not show any saving in the new process as compared with the old. Mr. Wean also states that when the conventional-type sheet mill has been properly developed "it will be extremely difficult for wide-strip-mill producers to manufacture at a lower cost than the ordinary sheet-mill producers." If, now, the wide-strip mill does not make better goods and cannot make cheaper goods, why did the sheet industry spend seventy-five million dollars to install them?

This is particularly pertinent as Mr. Jones agrees with me that under the present hot-strip practice 12 to 16 gage may be considered commercial limits in wide sheets. We all know, of course, that within those limits the conventional sheet mill is also very efficient.

Mr. Eppelsheimer disagrees with my warning to the industry in reference to possible patent troubles. He says that the American Rolling Mills Company is collecting royalties from several other steel companies and is perfectly well satisfied with the situation. He does not say, however, whether these arrangements are in the interest of the company or of the industry.

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# The Manufacture of Nickel-Steel Plate

By CHARLES McKNIGHT,[1] NEW YORK, N. Y., and W. G. HUMPTON,[2] COATESVILLE, PA.

*This paper deals with the manufacture, rolling, and inspection of steels containing between 2 and 3 per cent of nickel and which are used in boiler construction, and particularly with the manufacture of fairly large plates of from 1/4 to 1 1/2 in. in thickness. The physical properties of the metal are first discussed, following which details are given of its manufacture, beginning with the ingot phase and proceeding then step by step through stripping and reheating, rolling, flattening, inspecting and shearing, and finally, testing.*

NICKEL-STEEL plate has been employed since the early days of alloy-steel manufacture. It is used for circular saws and saw disks, structural material for bridges, etc., ship plate, protective deck plate and armor plate for warships, automobile-frame stock, etc. During the war large quantities were used as protective plate, not only for warships but for tanks, caissons, field-piece shields, etc. For many of these purposes the nickel was combined with other alloying elements, such as chromium.

In the past few years a new use has been developed for this material in the construction of steam boilers. While not strictly a new use, since nickel-steel boilers are still in service that were built over a quarter of a century ago, nevertheless the tonnage for that purpose has expanded remarkably since the use of nickel steel in 1926 by the Canadian Pacific Railway Company for the boilers of 45 locomotives. As a result of this successful application a large number of boilers subjected to high pressure have been built in whole or in part of nickel steel, and the production of this material has stimulated its use where a plate of high physical characteristics is desired, not only for boilers and pressure vessels, but for other structural purposes.

This paper deals, therefore, not with the whole gamut of nickel steels, but simply with those having between 2 and 3 per cent of nickel and no other alloying elements, such as are used for boilers, and is further confined to the manufacture of fairly large plates between 1/4 and 1 1/2 in. in thickness.

In general, however, the practice to be described is equally applicable to the manufacture of other alloy steels and other sizes. Essentially, the difference between the practice in manufacturing alloy-steel plate and carbon-steel plate is not due so much to the nickel or other alloying element contained as it is to the fact that alloy steels must be "killed" in order fully to develop their best characteristics.

## Physical Properties of Nickel Steel

While not strictly within the province of the paper, some consideration may properly be given to the physical properties developed in nickel steel. Table 1 shows the analysis and tensile properties required by a representative specification for nickel-steel boiler plate, the average results of 523 tests on such steel, and, for comparison, similar results on a carbon plate steel.

Primarily nickel steel is used because its strength is higher than that of carbon steel while its ductility is practically the same. But, in addition, the other qualities which are desirable, even necessary, in a boiler are developed with nickel steel to a higher degree than with any other material, so that it is peculiarly, almost uniquely, suited to boiler requirements.

These additional qualities are its physical characteristics at high temperatures, its excellent impact values, its resistance to embrittlement in boiler service, and its uniformity.

Physical testing of boiler materials at room temperatures and under usual conditions can at best be only an approximate guide to their suitability for boiler service. At best the working temperature of a boiler is some 200 deg. fahr. higher, in a temperature range where changes occur in the nature of the steel. But even worse, with the temperatures and pressures now being used, the steel enters the "blue-brittle" range, where an ordinarily soft and ductile metal unaccountably loses its toughness and becomes very brittle, although the strength is greater than when cold. A piece of boiler steel which can be bent double when cold will break off short at this temperature and the fracture will have the characteristic blue color which alike indicates the temperature and the derivation of the term "blue-brittleness."

TABLE 1 COMPARATIVE DATA ON NICKEL AND CARBON PLATE STEELS

*Percentage Analysis of 3 Per Cent Nickel Steel*

| | Average | Specified |
|---|---|---|
| Carbon | 0.163 | 0.20 (max.) |
| Manganese | 0.557 | 0.40–0.80 |
| Phosphorus | 0.021 | 0.045 (max.) |
| Sulphur | 0.029 | 0.045 (max.) |
| Silicon | 0.203 | Not specified |
| Nickel | 2.960 | 2.75–3.25 |

*Tensile Properties of Nickel and Carbon Plate Steels*

| | 3 per cent nickel steel Avg. 523 tests | 3 per cent nickel steel Specification | Carbon steel Avg. 385 tests |
|---|---|---|---|
| Ultimate tensile strength, lb. per sq. in. | 77,880 | 70,000 (min.) | 59,200 |
| Yield point, lb. per sq. in. | 47,550 | 0.5 × U.T.S. | 36,200 |
| Elongation in 8 in., per cent | 26.33 | 1,600,000/U.T.S. (min. 20%) | 28.64 |
| Reduction of area, per cent | 54.15 | 50 | Not determined |
| Izod impact, ft-lb. | 63.4 | ... | Not determined |

The superiority of nickel steel at these high temperatures is shown concisely in graphic form in Figs. 1 and 2[3] and only a brief reference can be made here to the resistance to corrosion and cracking of nickel steel.

## MANUFACTURE OF NICKEL-STEEL PLATE

During the steel-melting phase of the manufacture of nickel-steel plate it is necessary to use the ordinary precautions taken to insure the production of a good, sound steel, but otherwise the melting is not difficult. The nickel is usually obtained in part by charging nickel-steel scrap, such as shear scrap, and in part by the addition of metallic nickel to the charge. Since nickel is not oxidized during the progress of the heat, it is simplicity itself to hit within the specified analysis range.

Either the acid or basic process may be used, but the basic open-hearth seems to be more in favor at the present time, as the major part of the nickel steel for plates has been made on basic bottoms. The furnaces themselves are conventional in every respect, of from 50 to 100 tons capacity, and fired with oil or gas.

### The Ingot Phase

The handling of the metal in the ingot phase, important in the manufacture of any steel, is doubly so with the alloy steels, and the utmost care and minutest precautions are amply repaid later on by fewer defects and less rejections.

First, and most important, is the "killing" of the steel. Car-

[1] International Nickel Company.

[2] Metallurgist, Lukens Steel Company.

Presented at the National Meeting of the A.S.M.E. Iron and Steel Division, Chicago, Ill., November 14 and 15, 1928.

[3] For more detailed information on this subject see "Alloy Steel for Boiler Construction," Trans. A.S.S.T., 1928.

bon-steel plate generally is of the unkilled or "rimming" type of steel; that is, the silicon and other degasifying elements are purposely kept low and the metal holds in solution large quantities of gas. During solidification a portion of this gas escapes from the steel, but there still remains enough to cause in the ingot a large number of blowholes. The volume of these blowholes counteracts the voids caused by the shrinkage of the steel during

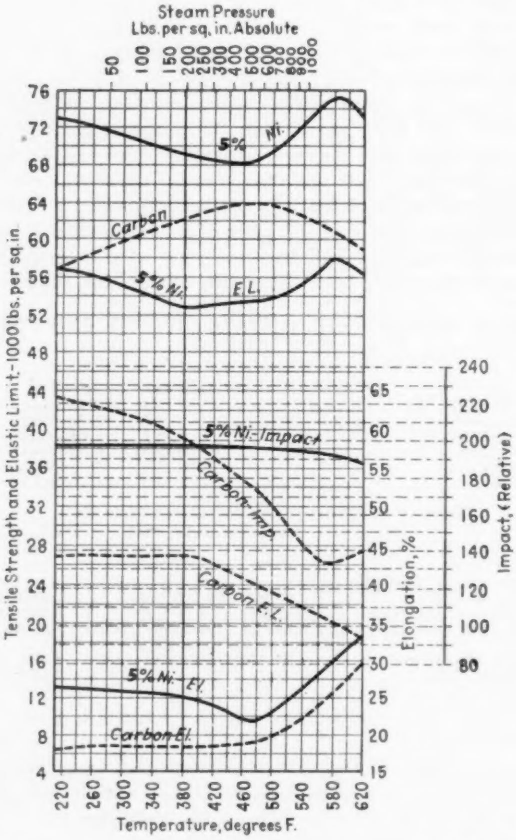


**Fig. 1** Comparative Properties of Low-Carbon and 5 Per Cent Nickel Steels at Different Temperatures and Steam Pressures

solidification, and therefore there is no "pipe" at the top center and running down through the ingot. In carbon steel the blowholes are welded up and leave little trace in the finished product of their original existence.

With alloy steels, however, such blowholes do not weld up satisfactorily. For this reason and others all alloy steels are "killed." This is accomplished by the addition to the metal in the bath or ladle of such elements as silicon, manganese, and aluminum, which eliminate most of the gases. The result of course is that the shrinkage of the molten steel causes a shrinkage void or pipe to occur in the top center of the ingot, but aside from this the ingot is sound and free from voids. In order to reduce and localize the pipe and also to insure sounder metal, it is customary with alloy steels to employ a refractory hot top on the ingot mold which, by keeping the steel hot at that point and allowing it to be the last to solidify, accomplishes the desired purposes.

Aside from the employment of the hot top, the design of the mold is most important, and the taper, wall thickness, and proportions are given careful consideration. A mold with fluted walls has recently come into favor and seems to give excellent results.

A satisfactory-sized ingot mold is 48 in. × 21 in. × 19,000 lb. An ingot from such a mold equipped with a hot top will have about 3000 lb. of metal to be discarded from the hot top.

In rolling plate by far the greatest number of rejections are due to surface defects, and an imperfection originally in the ingot surface will often persist through to the finished product. The greatest care is necessary in pouring to avoid such defects. Splashes, laps, stop pours, and mold pulls are all eliminated as much as possible. It is claimed that the process of bottom pouring, whereby a group of ingot molds are simultaneously fed from the bottom through a central downtake, results in a superior ingot surface. Such a system has, however, at least two serious objections. First are the unavoidable complications involved, such as setting up the bottom plates and runners and later removing the steel which filled them from the ingots; and second is the fact that refractory material is often cut loose from the runners by the stream of molten steel and becomes embedded in the ingot. An inclusion in an ingot resulting from such refractory material is often more serious than the minor surface defects the process is supposed to eliminate.

Therefore, while in the past bottom pouring has been largely employed, especially on deck plate of alloy steel, recently the trend seems to have been toward top pouring. When due care is taken to pour slowly and uniformly and to avoid splashes, the results have been quite satisfactory. Box pouring of two or more ingots simultaneously has given good results.

To assist in producing a good surface, mold washes are employed by some. These washes may be either the simple tar-smoke coating made by placing some tar on the mold stool or bottom, a tar or lime wash, or a wash containing flake aluminum. The latter has the dual advantage of giving a good, clean surface

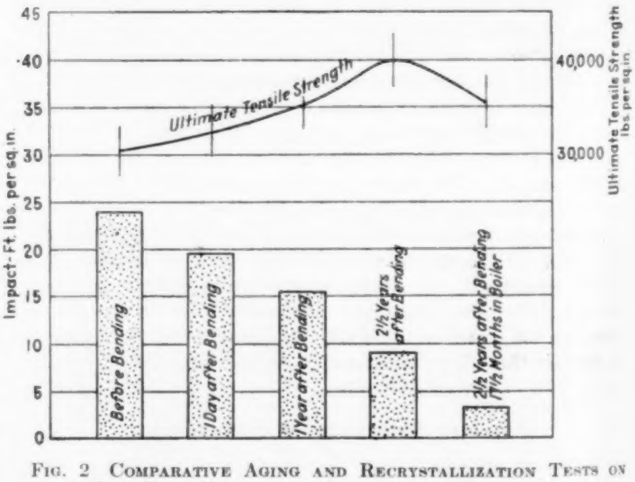


**Fig. 2** Comparative Aging and Recrystallization Tests on 5 Per Cent Nickel and Low-Carbon Boiler Steels

for the metal to lie against, as well as eliminating any small surface blowholes through the chemical action of the aluminum.

Another scheme employed by one of the largest alloy-plate producers was to place in the center of the mold before pouring a stovepipe of blue-annealed steel some 10 to 12 in. in diameter. This avoided all splashing and, as the stovepipe was melted quickly, there was no danger that it would be incorporated in the ingot.

## Stripping and Reheating

Paradoxically, large plate ingots of steel and fragile glassware require equally delicate handling after passing from the molten to the solid state. It is desirable, therefore, that an ingot should not be allowed to become cold until after some work has been done on it.

As soon as the ingot has had time to solidify throughout it should be stripped from the mold, but this should be done, if possible, where there is no likelihood of the tender outside surface, being chilled. It is preferable to remove the ingot and mold to the soaking-pit building and there strip the ingot and place it immediately in a pit.

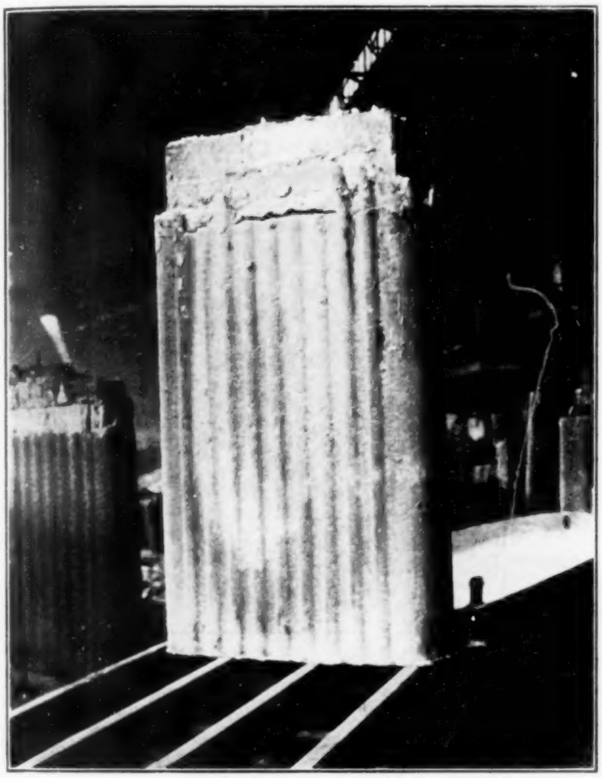

FIG. 3 48 × 21-IN. (19,000-LB.) CORRUGATED NICKEL-STEEL INGOT (C, 0.21; Mn, 0.75; P, 0.010; S, 0.020; Ni, 2.09; Si, 0.18.)

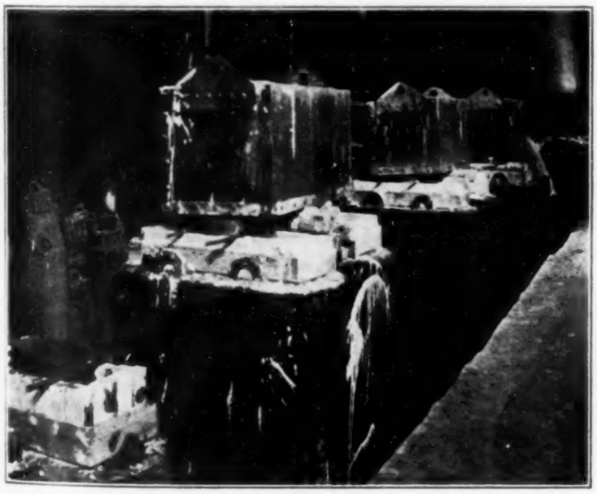

FIG. 4 MOLD SET-UP SHOWING BOX POURING OF 48 × 21-IN. (19,000-LB.) NICKEL-STEEL INGOTS

The pit should be as nearly as possible at the temperature of the ingot, and for an hour or more—for the usual-size ingot—no effort should be made to increase the heat. This time should be allowed to equalize the temperature beween the hot interior and the colder exterior of the metal. Then the heat should be gradually applied and the ingot brought up to rolling temperature slowly, using a smoky flame. If too great a heat or a highly oxidizing flame is used the original scale on the ingot will be washed off, and it will subsequently be found that it is extremely difficult during rolling to clean the plate of the second scale which forms.

FIG. 5 PLATE-TURNING DEVICE ON 206-IN. MILL TABLE

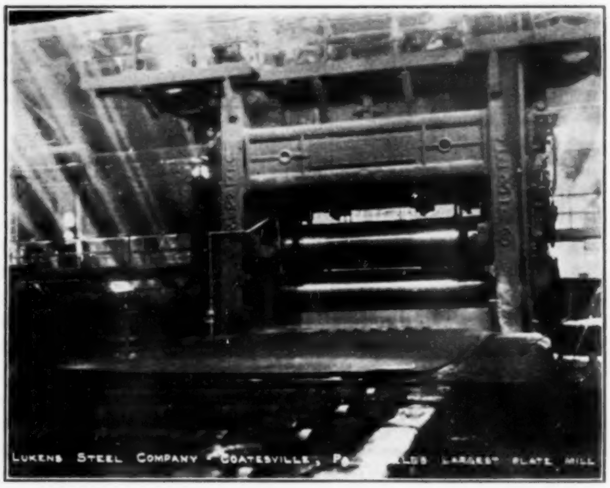


FIG. 6 206-IN. FOUR-HIGH REVERSING MILL

If it is impossible to heat the ingots immediately, they should be placed in a spare pit where they will be protected from chilling and where the equalization of heat can take place. At all events, the ingots should not be allowed to become cold.

The initial rolling temperature of nickel steel for plate should be about 2150 deg. fahr.

### Rolling

Two methods of rolling plate are in vogue; either the ingot is rolled directly into plate in one operation, or it is first slabbed—i.e., reduced about one-half in thickness—and the slabs reheated and rolled to completion, usually on another mill, but occasionally on the same one. The slabbing process has some advantages. More cross-rolling of the ingot can be done, and rolling in two directions gives better equalization of physical properties. Also, if necessary, the slabs can be allowed to cool and surface defects chipped out, after which the plate is finished. This is advantageous when rolling nickel and other alloy steels which are peculiarly liable to surface defects.

It is essential to employ some means for cleaning the plates during rolling. With carbon-steel plate water is sprayed on the plate during the latter part of the rolling, and during the last few passes salt is scattered over the surface; this causes a sudden evolution of gas as the rolls press it against the hot metal, which blows off any loosely adherent scale. Nickel steel requires more strenuous measures. In some cases coal dust has been substituted for salt, and in Great Britain broom, heather, brush, and twigs have been used. Considerable experience has shown, it appears, that the best cleaning is accomplished by the use of high-pressure water, salt, and old burlap soaked in brine. The water is directed from a series of jets at the surface of the plate as it passes through the rolls; the salt is applied at any time during the rolling and quite generously during the last few passes, while the brine-soaked burlap is thrown by men, especially stationed for that purpose, in such a way as to hit the spots which need cleaning just as the rolls strike them. Care and attention are productive of better results than is the choice of cleaning materials.

Fig. 7 Straightening Rolls of 206-In. Mill

Such methods of cleaning, used for many years in the production of protective deck plate, have had one glaring defect. They clean only the top surface, the theory perhaps being that the embedded scale will fall from the bottom surface in due time. This is not the case, and although it is not absolutely essential that both surfaces be good for deck plate, it is for boiler and firebox plate. The company which has rolled the largest tonnage of nickel-steel boiler plate has apparently solved this problem by the use of a very simple, cheap, and ingenious device with which the plate is turned over on the tables during rolling, whereby both top and bottom surfaces may be observed and cleaned.

The rolling process itself, as pursued at the plant just mentioned, is as follows: The heated ingot is first given one or two passes in a longitudinal direction, the purpose of which is to "sadden" the ingot, followed by rolling for width. When the ingot, or slab, has been broken down to about one-half its original thickness and to a size suitable for recharging into the soaking pits, it is removed from the mill and allowed to cool prior to inspection. It is then chipped with pneumatic chisels to remove serious surface defects, although in many cases it is taken to the machine shop and the entire top and bottom planed off. This drastic and rather expensive treatment has seemed in many cases to be justified by the eventual results.

Fig. 8 3 Per Cent Nickel Steel as Rolled. × 100
(Specimen taken from a 273 × 145 × $^{12}/_{16}$-in. front barrel sheet.)

Fig. 9 Same Steel as in Fig. 8 After Normalizing. × 100

The cleaned slabs are carefully reheated and finish-rolled on a four-high reversing-type mill. When the plate has been subjected to the heavier drafts and after the top surface has been cleaned by the use of burlap and salt, it is run into the apparatus set in the table and turned over so that the bottom surface can be cleaned and rolling completed.

### Flattening

Ordinary carbon-steel plate exhibits such a slight tendency to harden when cooled rapidly that the finishing temperature

of rolling and the quenching effect of the flattening rolls make comparatively unimportant changes in the tensile properties of the metal. Alloy steels are quite different, and important effects can be obtained by varying the finishing temperature and the rapidity of cooling.

Generally speaking, the best combination of physical properties is obtained with nickel-steel plate if it is not cooled through the critical range too quickly. For that reason it is well to plan on finishing actual rolling at a good red heat (1450–1500 deg. fahr.) and allowing the plates to cool slowly through the critical range on the cooling bed by piling one plate on top of another or by taking them off the beds, piling and covering with sand, and then restraightening.

There is a growing conviction among plate users that plates, even of carbon steel, should not be used in the "as rolled" condition, and that principles of safety and efficient use dictate a normalizing of plates prior to use. It is not known that this heat treatment is being given, except sporadically, by any mill, but it seems to be accepted that sooner or later all plants will be equipped with furnaces sufficiently large to heat-treat all plates. Both the manufacturers and users of alloy-steel plate will be benefited by such a change, though it must be admitted such practice would be more of the nature of a refinement than a necessity. In this connection it is of interest to note that the plates of nickel steel for the latest locomotives were ordered by the railroad to be normalized after rolling.

The gage of the plates has also an effect on the hardening, and for that reason the lighter-gage plates are somewhat lower in carbon than the heavier ones. The thinner gages, finishing colder, would for the same analysis give higher tensile values, so that the minimum tensile strength possible with a 2.0 to 3.0 per cent nickel steel would still be considerably higher than for a corresponding carbon steel.

### Inspection and Shearing

When inspecting alloy-steel plates, the defects to look for are "snakes" and pits or heavy embedded scale. Well over 50 per cent of the necessary rejections will be for these causes.

The reason for the existence of pits and scale are apparent, but why snakes appear is still, the authors frankly confess, a mystery. Any theory is good until it fails to be supported by facts. So far no specific cure for them has been found, and it would seem they are simply in the nature of a disciplinary dispensation to keep the steel maker from finding his career a bed of flowery ease. The use of great care during the pouring of the ingot and the avoiding of sudden drafts on the ingot just after it has been stripped seem to have a beneficial effect in this regard.

The only method of dealing with snakes, when they occur, is to grind them out. This practice has been permitted by the United States Navy for a number of years, and while it is still not acceptable to some purchasers, it seems to be an unnecessary hardship on the steel mill to be forced to reject plates which are otherwise good. The recommended method of grinding, if the snakes are not too long, is to use an abrasive wheel of a diameter sufficiently great that the trough or groove so ground will not have sharp corners. To be sure of removal, the clean ground surface should be etched with acid (hydrochloric 1–1 in water is good) to develop any remnants. If no trace of the seam remains after this treatment and the plate is not reduced in thickness beyond permissible limits, it should be considered good delivery.

Pits and scale marks are left to the discretion of the inspector. If serious or too frequent, they are cause for rejection; if only occasional and of slight depth, they may be accepted.

It is at this point that the fact that alloy steels are killed steels is first apparent. The pipe in the top of the ingot, unless the slab was cropped, still occupies the same proportion of the plate, and this portion must be rejected. This is the reason for the comparatively low yield on alloy-steel plate. With the rimming" carbon steel there is no pipe, and the percentage of usable product to total weight will run in the neighborhood of 70 per cent. With alloy steels this ratio will be nearer 60 per cent. In both cases, of course, the side and bottom shear scrap is the same.

It often requires considerable ingenuity on the part of the layer-out to fit his sketch on a plate and avoid on the one hand the pipe and, on the other, whatever surface defects there may be.

### Testing

The usual tensile tests are required, which include longitudinal tests from various parts of the plate as well as a top transverse

Fig. 10 Full-Bend Test on 3 Per Cent Nickel-Steel Boiler Plate

test. The majority of specifications call for the tensile values to be determined from a bottom longitudinal specimen and the bending properties from a top transverse specimen. It might be well to point out the difference between the tensile tests in a killed alloy steel and a rimming or open steel. The former, due to being killed, is very uniform, showing little difference between the tensile test taken from the top and that taken from the bottom, as well as little differences between the transverse strength and the longitudinal strength. The open steel, however, which is from its nature a segregating steel, will show considerable variations between the top and bottom tensile tests, as well as between the longitudinal and transverse tests. By the same token, the variation in analyses of the nickel steel between any two parts of the plate or ingot is very much less than in carbon steel, which results in a more uniform product.

Microscopic examination is rarely called for. The main defects which show up under such examination are laminations and large grain. The latter is due to high finishing temperatures, and is of no importance if the steel successfully passes the tensile and bend tests.

Laminations are of two kinds. The first is due to a segregation of the pearlite and ferrite constituents of the steel into layers, and is quite common in all plates. It is probably due to the unidirectional work done on plates and is rarely a serious defect. The other is an actual separation of the metal and is usually caused by incomplete cropping of the plate, so that a portion of the pipe remains.

### Conclusion

Emphasis has been placed throughout this paper on the defects occurring in the manufacture of nickel-steel plates, but which, for that matter, are common to all alloy-steel plates. The danger is that this emphasis will give the false impression that such plates are difficult to make and of doubtful reliability.

Such is not the case. Without going further, the subject has been briefly summed up by one of the largest users of nickel-steel plate, who reported that the surface of the nickel-steel plate delivered to him was the equal of that of carbon-steel plate, and stated that, disregarding the alloy entirely and comparing them on an equal basis, the nickel-steel plates were better than the carbon-steel ones used at the same time, and that there were more rejections of carbon steel than of nickel steel. This, however, is not meant to imply that the purchaser should expect a better surface on nickel steel than on carbon steel.

## Discussion

W. J. MacKenzie.[4] Experience has taught us that high-grade alloy steels of today are possible because each and every operation from the selection of the charge, the melting, refining, pouring, heating, rolling, etc., has been carefully studied. However, many problems are still without a definite answer. For example, today for the first time a real study of slags, their composition, reactions, etc., is being made. Up to this time we have only known their general behavior. Further, there are the unknown constituents of steels, the so-called dissolved gases, the nitrides and oxides. The writer believes the day is not far distant when we shall be able to explain the different dynamic results obtained on different heats of the same chemical analysis by a more intimate knowledge of the chemistry of these oxides and nitrides, and shall be able to state which are harmful and which are not.

In the paper mention is made of a satisfactory ingot mold for plates, which is 48 × 21 in. and casts an ingot weighing 19,000 lb. The statement follows that the hot top on the ingot will contain about 3000 lb. of metal. Then later it is stated that the usual yield on alloy plates is about 60 per cent. In a conversation the writer had with Mr. McKnight he pointed this out and explained that in this 19,000-lb. ingot more than 3000 lb. of hot top is discarded to get to sound steel. Or, if only the hot top were discarded the yield would be 84 per cent instead of 60 per cent. This leads the writer to wonder why larger hot tops are not used, and if the ingots are poured with the big end up or down. For our purposes the big-end-up mold seems to work the better, and our hot tops are sufficient to take care of all piping and segregation.

Some mills roll their alloy plates direct from the ingot, while others double-convert. We double convert all our bar stock that we furnish in rounds, squares, and flats. The ingots are rolled into billets, which are pickled and chipped. They are then reheated and rolled into the finished bar form. Pickling is especially helpful to us because it shows up all surface defects, which sometimes cannot be seen through the scale, and this is particularly true of the nickel steels because of their greater tendency to scale. The writer wonders if pickling the billets or slabs for plates is employed.

In conclusion, the writer is glad to note the interest being shown in alloy steels for high-strength work other than automotive. They have a definite place, and will find an ever-growing field for their application. The steel mills are all glad to help on any problems presented, and maintain large staffs of metallurgists for this purpose.

William A. Newman.[5] Just what practical results the Canadian Pacific Railway Company has obtained with the use of nickel-steel boiler plate may be of interest.

Early in 1926, when we decided that we would increase our standard boiler pressure from 200 lb. to 250 lb., we anticipated that our boiler maintenance would be more difficult and expensive, but were willing to accept the more adverse circumstances in view of the greater capacity and efficiency that could be obtained by the use of higher boiler pressures. Forty-four locomotives were constructed during 1926, and somewhat to our surprise the increased maintenance difficulties have not developed; in fact, our 250-lb.-pressure locomotive boilers constructed of nickel steel actually gave less trouble through leaks than is the case with boilers carrying the maximum pressure of 200 lb. per sq. in.

During fabrication nickel steel is no more difficult to drill than carbon steel, but is naturally somewhat stiffer to roll. There is necessarily a certain amount of hand flanging in a locomotive boiler in order to set up portions of the boiler tightly in contact with the adjacent plates or foundation rings, and we do find that it is much harder to set nickel steel than it is carbon steel. Once the plate is set, however, it stays that way and this is also true of calking the plate, it being slightly harder to work; but as was stated for the flanging, once the material is worked to its final position it remains that way, to which, of course, we attribute the excellent service that we have had from our boilers in that they have not developed the minor leaks, etc., that all locomotive boilers are more or less addicted to with the constant working and vibration to which they are subjected.

Altogether from early in 1926 up to the present the Canadian Pacific Railway Company has put into service 72 locomotives, including two locomotives operating under 275 lb. pressure, in which nickel steel has been used for all the main-course plates and also to a certain extent for tube sheets, firebox, and wrapper sheets. The use of nickel steel was of course purely experimental, and was our answer to the increasing difficulties of building large locomotives and keeping them within weight limitations. Our experiment has been successful in every way so far as the actual fabrication and operation of boilers is concerned, and incidentally the weight saving that was effected in boiler plates amounted to approximately 28 per cent.

C. A. Seley.[6] The entry of alloy-steel plates into steam-boiler designs, particularly those of locomotive boilers for railway use, has mainly been brought about by weight considerations in connection with large-capacity requirements in railroad service. The higher tensile strength afforded has permitted an increase of steam pressure without proportionate weight increase.

The C. P. R. locomotives as quoted in the paper carry 250 lb. steam pressure as against 200 lb. for approximately similar boiler designs built of carbon steel. We hear of somewhat higher pressures being employed in stayed-plate locomotive boilers up to 275 lb. and possibly to 300 lb.

Quoting from the fourth paragraph of the second page of the paper: "With the temperatures and pressures now being used, the steel enters the 'blue brittle' range, when an ordinarily soft and ductile metal unaccountably loses its toughness and becomes very brittle, although the strength is greater than when cold." As stated, an unsafe condition is entered into when steam temperatures approximating those of the so-called "blue brittle" range are employed with the use of carbon steel.

In the C. P. R. boilers mentioned, alloy steel was used in the shell and outer sheets, which were not increased in thickness over previous designs. These sheets are swept by the steam and water and the temperature of the 200-lb. saturated steam, as formerly used, was 388 deg. fahr. That of 250-lb. is 406 deg., an increase of 18 deg. or 4.5 per cent for a 25 per cent pressure increase. If

[4] Vice-President, Interstate Iron and Steel Company, Chicago, Ill.

[5] Chief Mechanical Engineer, Canadian Pacific Railway Co., Montreal, Canada.

[6] Consulting Engineer, Locomotive Firebox Company, Chicago, Ill.

we go to 300 lb. it requires a further addition of 14 deg. or 422 deg. fahr. steam temperature.

The word "brittle" is ordinarily defined as "easily broken, apt to break, fragile, not tough, or tenacious." One would infer from the language of the paper that the steel as ordinarily applied in our boilers becomes brittle in some of the above senses with even moderate increases in pressure and temperatures.

The writer finds it difficult to accept the conclusion in the paper on this feature, even while assuming all the possible advantages set forth in favor of alloy steel.

We are all aware that steel properties vary with temperatures and that the tests as outlined in various specifications are to be made at normal room temperatures and that a so-called factor of safety, or more appropriately, perhaps a factor of uncertainty is used in design. Some have been forthright enough to call it a factor of ignorance.

If alloy steel is used for firebox material, there is a somewhat greater range of temperature of the sheets exposed to fire. If the surfaces are clean the resistance to the passage of the heat through the plates is very small indeed. A resistance is built up with scale on the water side, adding somewhat to the sheet temperature engaged in the transfer of heat to the water, and upsetting all the scientific deductions by the extreme variability of thickness and resistance to heat conductivity which is affected thereby.

Thus is permitted a further excursion into the "blue brittle" range of temperature, of an entirely unknown and variable amount, for the firebox sheet, rendering it more and more brittle and unsafe, if the language in the paper is to be accepted as stated.

Nevertheless, and notwithstanding, more or less of the 70,000-odd locomotives in the United States have thus been operated these many years in an unsafe condition, although not evidenced by failures that can be traced to operation in the "blue brittle" temperature range.

We all know that firebox sheets crack and fail miserably sometimes, but it is plain to engineers that the locomotive boiler is the most abused steam generator in use, particularly in its terminal handling, where probably 90 per cent of the general maintenance—listing as such, cracks, leaks, sheet renewals, broken staybolts, etc.—is initially caused by stresses set up in terminal handling and not in normal operation.

Any development and improvement in boiler metals that will have a tendency to minimize the effects of these conditions is surely very laudable and worthy of most serious consideration of this and other engineering societies.

Leon Cammen.[7] Several discussers have made reference to leaks on locomotive boilers. Such boilers leak because the rimmed steel of which they are made is steel which contains gases, chiefly carbon monoxide, at the time it is being chilled. The result is that the steel is full of small bubbles, which, contrary to the statement of the authors, are not squeezed out when the steel is rolled, but are changed in shape. Because of the presence of carbon monoxide the surfaces of these bubbles are not oxidized. If there were any oxidation the carbon monoxide at that temperature would immediately convert itself into carbon dioxide. The bubbles cannot weld 100 per cent without dissolving the carbon monoxide, which of course is impossible. Therefore a bubble will weld up to about 90 per cent perhaps, the remaining 10 per cent being a tiny cavity filled with gas under very considerable pressure.

The action of this tiny bubble with reference to shocks, and particularly to vibrational stresses, is exactly the same as would be the action of a notch in a piece of steel. In other words, a plate of rimmed steel contains throughout its body a series of spots so arranged that the development of stress, strain, and failure is predetermined by the shape and direction of the bubble. Sooner or later it will begin to crack, and if several such bubbles happen to be located one next to the other across the thickness of the plate, a leak will result.

The nickel steel described in the paper is a killed steel, or one which is thoroughly degasified. There is no carbon monoxide in it at the time the steel sets, and therefore it is not so subject to leaks and gives less trouble than ordinary plate steel. If we took the same pains and made the carbon steel a killed steel, it would probably be free from bubbles and at least as free from leaks if not as strong as the nickel steel. It would, though, have a greater tendency to oxidize than does nickel steel.

[7] Consulting Engineer, New York, N. Y.

# Rolling-Mill Lubrication

By L. P. Tyler,[1] Pittsburgh, Pa.

*The author confines his discussion to those modern installations where lubrication is effected by means of a system which automatically circulates a single lubricant. He first considers the mill members best adapted to such lubrication, following which he outlines the conditions to be satisfied for correct lubrication. The requirements to be met by the lubricant are then enumerated, and instructions are given for its application and handling. Finally the advantages of such a system in the way of economy and in the compactness of design it permits are pointed out.*

PROBABLY no industry offers the variety of problems to test the skill of the lubrication engineer than does the iron and steel industry. Rolling-mill machinery, in particular, presents many unusual problems of lubrication because of the severity of service under extremely unfavorable operating conditions.

Oils and greases should be carefully selected to meet the variety of operating pressures, temperatures, speeds, and contaminating influences of dust, dirt, scale, and water to which they will be subjected on the various types of rolling-mill equipment.

In addition, it is important to select a method of application which will provide continuous film formation with the proper lubricant at maximum economy and with due regard to safety and conservation of the operator's time.

Equal care must be exercised in conditioning oil which is re-used, and in its handling and storage, to preserve the original purity and cleanliness of the lubricant for as long a period as possible.

The application of these principles to the definite problem of the lubrication of modern rolling-mill driving equipment will now be considered.

In recent years the general introduction of the electric drive has effected some very marked changes in the rolling of steel. Changes in methods of rolling have altered the power requirements, increasing the loading and mill speeds so that mill tonnages today are much greater than they were ten and even five years ago. The art of rolling steel has usually led and seldom lagged in the advances of the iron and steel trade. From 1783, when Henry Cort obtained his patents for puddling iron and rolling it into bars, the design of machinery has steadily improved, both in power and accuracy. At no period probably have these advances been so rapid as within the past five years.

The purpose of this paper is to indicate how the science of lubrication has fitted into the scheme of progress. Probably in no other industry is the necessity for continuous operation of more importance; and in no other is there greater loss as a result of forced shutdown. Increase in the size of ingots rolled, the development of high-speed motor-driven continuous mills, and greater competition in the steel market have further enhanced the value of reliability as well as operating economy.

Continuous operation at minimum cost per ton is the result sought. Many forces militate against this objective, such as roll changes, short orders, furnace operation, mill breakdowns, and repairs. Correct lubrication as a factor in maintaining continuous operation is therefore of great importance. The automatic features of the modern mill have substantially reduced the cost of operating labor. It is therefore desirable that the auxiliary features which serve the main purpose shall assist in economical developments.

[1] Vacuum Oil Company.

Presented at the National Meeting of the A.S.M.E. Iron and Steel Division, Chicago, Ill., November 14 and 15, 1928.

Discussion will be confined to those modern installations where lubrication of reduction gears, mill pinions, and their bearings is being secured with a single lubricant applied by an automatic-circulation oiling system. Those members of the mill which, in the author's experience, can be served by a system of this sort would include those mentioned in the following paragraphs:

## Mill Members Best Adapted to Lubrication by an Automatic-Circulation System

*Pinions and Their Bearings.* The function of the pinions is to divide the power supplied by the motor through a single shaft or spindle among the rolls and to control their direction of rotation. Their shafts run in plain bearings contained in the housings. In the oldest form the pinion teeth ran straight across the face, but later it was found that smoother operation resulted from dividing the face into two parts and staggering the teeth of the two halves. Today pinions are made with helical or "herringbone" teeth, and are accurately machined and generally heat-treated. This tends to materially reduce vibration inasmuch as some parts of the teeth are always in contact and transmission of the power is continuous. It also permits much higher peripheral speeds. Pinion speeds are likely to vary from 10 to 500 r.p.m. and higher. A typical high-speed pinion on a strip or skelp mill will have a pitch diameter of 12 to 14 in., a face width varying from 20 to 28 in., and a circular pitch of approximately 2 in. At the other extreme a typical pinion for a large blooming mill would be approximately 60 in. long between the necks, and have a pitch diameter of 40 in. and 14 teeth.

Early lubrication practice was to give the pinions an occasional dressing of pine tar, plumbago and tallow, or other mixture of grease. This practice was followed later by having the housings cast in one piece so as to form an oil bath in which the bottom pinion was partly submerged. This has in turn been followed by the present practice of spraying a heavy-bodied oil under pressure to the teeth at the line of mesh.

The design of the pinion bearings has likewise undergone some very decided changes. In the early stages these bearings consisted of babbitted cast-iron shells with pockets cored for the storage of grease for the lubrication of the journals. The advent of cut-tooth pinions necessitated a greater degree of accuracy in the mounting and alignment, as well as more efficient means of lubrication. It was generally believed that a heavy oil or gear shield was necessary for the pinion-tooth lubrication and a lighter oil for the bearings. This necessitated a design which would separate the two lubricants, a rather difficult task. To overcome this, oils have been provided for the lubrication of pinion teeth as well as the pinion journals. The use of a single lubricant for both pinions and bearings simplifies the design and saves 10 to 12 in. in the length of the pinions. Babbitt is used as a bearing metal on practically all installations.

*Reduction-Gear Drives.* The present high-speed mills have introduced accurately cut single- and double-helical reduction gears in single or multiple reductions, serving one or more roll stands. The horsepower transmitted will vary from 500 to 5000.

The bearings for the gear drives are generally of the ring-oiled type, although roller bearings have been used on a number of recent installations. Here again the bearings were, until recently, designed for the use of lubricants on the gear teeth different from those on the bearings. The use of a single lubricant permits simplification in design with a material decrease in bear-

ing centers, which latter is important in the elimination of shaft deflections.

*Roller Bearings on Roll Necks.* The recent progress made in the application of roller bearings on the roll necks of rolling mills and also on pinion stands is worthy of note. Their correct lubrication is simpler and much more economical than the former design. Owing to their location it is not always desirable to tie in the roll-neck bearings with the oiling system serving the gears and pinions. Experience has shown that where they are subjected to severe washing action the water is readily carried into the system on oil-lubricated bearings. This may later be overcome by improved sealing arrangements.

### Correct Lubrication as Related to Present Problem

Correct lubrication results from the complete and continuous separation of the rubbing surfaces of the gears, pinions, and their bearings by an oil film of sufficient strength to resist the pressures, with minimum fluid friction. There must be arrangements for a continuous supply of clean, cool lubricant of the proper quality without waste.

Correct lubrication as related to the present problem must satisfy the following conditions.

1 *Reliability in Terms of Permitting Full and Continuous Production.* There must be assurance of a sufficient supply at all times of the proper lubricant to permit normal operating temperatures of gears, pinions, and their bearings. The mechanical features of the system itself should introduce no elements in which breakdowns are likely to occur.

An important advantage, as noted above, resulting from the use of a single lubricant is the elimination of the danger of contamination of the gear lubricant with the bearing lubricant, and vice versa. There is always a tendency for this transfer regardless of the care exerted by the manufacturer in sealing the bearings and equipping them with slingers and oil-drain grooves.

The frictional heat developed between the meshing teeth of the gears spreads to the bearings and gear case. Where a circulating oiling system is not employed, all of the heat developed must leave by radiation from the gear case. The difference between the temperature of the gear unit and that of the room is termed "frictional temperature." Gears operating at high speeds and lubricated by the splash of heavy oils often develop heat so rapidly that the frictional temperature becomes excessive. Under such conditions a circulating oiling system permits a flow of oil to the gear teeth, and the oil therefore becomes a coolant as well as a lubricant, radiating the heat to the atmosphere in its passage through the system.

The ring-oiled bearings of the drives are in effect a miniature automatic-circulation oiling system. Their limitations are the small volume of oil in service and inability to control the rate of feed. In large-size, high-speed, and heavily loaded bearings the pumping capacity of the rings may be less than that required to assure normal operating temperature. The modern system of lubrication offers a means of

(*a*) Changing the oil automatically and continuously
(*b*) Maintaining a constant level
(*c*) Varying the feed to meet the operating condition.

These result in a supply of clean and cool oil in sufficient quantity to maintain a strong supporting film, and also act as a coolant.

2 *Maximum Life of Equipment.* With the older machinery, frequent replacements were necessary and were not so expensive; but with the higher cost of new machinery, replacements are costly and shutdowns seriously interfere with production. The continuous action of supplying and withdrawing a fluid lubricating medium to and from the gears, pinions, and their respective bearings, permits the immediate removal of dust, mill dirt, scale, and other solids which act as abrasives, producing rapid wear.

3 *Lower Operating Costs.* Under this item should be considered the smaller consumption of power and the reduction in oiling labor and in the cost of lubrication. The rapid absorption and removal of heat by a cool fluid lubricant, together with minimum fluid resistance, produces low operating temperatures and maintains the proper alignment of the machine parts. This assists materially in the reduction of frictional losses and therefore permits high operating efficiency.

It is a well-known fact that the movement of the roll necks in their bearings, the pinions and their bearings, the driving gears and bearings as well as spindles, couplings, etc., imposes a very considerable frictional resistance, depending upon the design and operating conditions of the mill. Numerous tests have been run with the desire to determine exactly the power required to roll steel of various sections, and also to determine the frictional resistance of the moving parts. Reliable tests show, for instance, that the total power developed by a reversing-mill engine is distributed about as follows:

| | Per cent |
|---|---|
| Actually deforming the steel | 30 |
| Overcoming idle friction of the engine parts | 27 |
| Overcoming roll-journal friction | 13 |
| Overcoming acceleration of the parts in reversing | 21 |
| Overcoming pinion and spindle friction | 9 |

The development of roller bearings capable of sustaining the loads involved has of course materially reduced the power required in overcoming roll-neck friction. On continuous mills the power generally required in overcoming pinion, gear, and spindle friction runs from 12 to 15 per cent of the total power delivered. Recent tests on modern strip mills, oil-lubricated and equipped with the latest refinements, indicate a power requirement of about one-half that used in ordinary strip mills of corresponding sizes. An additional factor is the elimination of any undue starting torque, particularly in cold weather.

The cost of labor in attendance on a well-designed modern system is very small, the requirements being merely periodic inspection of the various oil-flow indicators, thermometers, gages, etc.

Due to the care exercised by the manufacturer in the design of bearings as well as gear and pinion housings, the mechanical losses of oil are practically nil.

### Application and Handling of the Lubricant

Primarily the lubricant is applied by means of a circulation oiling system. The system consists essentially of

1 A main supply line with branches to the various elements to be lubricated
2 A common return line into which drain the individual returns from each element
3 A suitable return tank to rest and cool the oil, and separate the heavy impurities and water
4 A means of cleaning and purifying the oil and pump
5 Clean-oil storage capacity.

The oil is applied to the gears under a pressure of 20 to 30 lb. per sq. in. by means of properly designed spray nozzles. These nozzles deliver the oil to the gears close to the line of mesh so that at the moment of contact the gear teeth are generously supplied with lubricant. The oil to the pinions is supplied at the top of the housing and cascaded into the engaging teeth by means of baffle plates suitably arranged. Suitable regulating devices permit control of the oil flow, and sight-flow indicators enable the operator to detect at a glance the quantity of flow. Suitable return piping drains the oil from the bottom of the gear case or pinion housing into a large return tank. Supply lines and regulating sight-feed oilers also furnish clean, cool oil to the

bearings, and the oil is returned from the bottom of the bearing reservoir to the return tank.

After the oil has done its work it should be given a short period of rest. This is for the purpose of dropping out solid impurities and water. This is accomplished in the return tank, the size of which depends of course on the volume of oil which it is necessary to circulate.

Additional cleaning is given the oil by some arrangement for bypass purification intended to assure the thorough and complete removal of water and insoluble impurities.

A clean-oil supply tank is used to store the conditioned oil and to assure a generous supply of lubricant at all times. This also permits the oil to cool, thus maintaining its original viscosity.

### Requirements to Be Met by the Lubricant

The problem of selecting the proper lubricant for steel-mill drives is basically composed of the following factors:

1 The lubricant must possess sufficient body to establish a film on the working surfaces of sufficient strength to resist rupture by the unit pressures imposed. These pressures are most severe on the engaging teeth of the pinions because of the shock loads to which these parts are subjected. An examination of the power-load curves on the motor drives indicates this feature, in addition to which the energy given up by the revolving masses must be considered. There are variables such as draft, temperature of the material, roll condition, etc., which make it extremely difficult to calculate, even on similar mills, just what this condition of maximum loading on the pinion teeth will be. It is therefore logical to select an oil which, by its body and adhesive characteristics, offers the maximum factor of safety against film rupture.

This consideration is particularly important in selecting an oil for the lubrication of the driving equipment for the modern continuous wide-strip mills. The mill builders emphasize the desirability of exact equalization of working-roll diameters to prevent slippage between the rolls and the metal or within the metal itself. With unequal roll diameters the spindle torque and the pinion tooth pressures may be sufficient to cause rapid pinion wear. This is particularly true in rolling wide, thin material, and on these mills the requirements for pinion lubrication call for an extremely heavy-bodied oil.

At the same time, a liberal proportioning of the pinion face with the resultant reduction in unit tooth pressure is highly desirable.

In this connection it is very seldom found that the oils selected are too heavy to take care of the bearings properly, inasmuch as the working clearances generally allowed are sufficient to accommodate these oils under working temperatures.

In addition to its function as a lubricant, the continuous washing of the gears and pinions with a cool, fluid lubricant maintains clean contact surfaces and results in a cooling action.

2 The lubricant must be adaptable for use in a circulation system. This circulation system involves the constant use of the same quantity of oil. It is therefore obvious that a properly selected, carefully manufactured oil will result in the greatest degree of dependability and economy.

The natural enemies of lubrication which the oil must combat are heat, air, water, and solid impurities. Air and heat cause a certain amount of oxidation of the oil, forming products, some of which are soluble and others insoluble. Water combines with products of oil oxidation and other foreign impurities to form emulsions in the oil. These factors are overcome by (*a*) the use of a high-quality oil possessing maximum chemical stability, (*b*) by provision for the removal of water and solids by heating, settling, and cleaning, and (*c*) by the reduction of soluble oxides by cooling and settling.

Where water is a factor, the roll-neck roller bearings should be separately lubricated by a good grade of grease of the proper consistency. Sufficient pressure should be applied to the grease to maintain a very small leakage from the seals so as to prevent any infiltration of dirt, scale, or water. It is also desirable to remove these bearings periodically and give them a thorough cleaning with light oil.

### Conclusion

The present systems which have been applied to blooming- and universal-mill pinions and bearings, as well as the drives, pinions, and bearings of continuous mills, are the outgrowth of the demand by both the steel-mill operators and equipment builders for a lubrication service which would meet modern mill practice. The last word has not by any means been said. Improvements in the design, manufacture, and placement of the machine parts, as well as in roll construction, temperature control, etc., will result eventually in the use of lighter-bodied oils than are employed at present, with the improved economy which this involves.

The ultimate economies from the use of a single lubricant are not all confined to operation. The practice permits of compact design, smaller gear and pinion housings, and the elimination of elaborate bearing seals and grooving.

In conclusion, it may be stated that the lubrication of modern high-speed mills is of great importance, has possibilities for substantial economies, and is worthy of the most careful thought and planning.

## Discussion

E. A. Franke.[2] In the lubrication of journals on locomotives we have been using a soap grease which is half soap and half oil. We have had trouble from the failure of locomotive axles due to the high operating temperature. Tests show this to be in excess of 400 deg. fahr. What has been the experience of the author with grease on heavy machinery?

W. D. Hodson.[3] We have specialized on mill work, and we question the possibility of making one type of lubricant function properly for all kinds of loads, speeds, temperature conditions, etc. We have found it necessary to use three different types and to use different consistency numbers for each type.

S. M. Weckstein.[4] In September, 1927, we installed what was the first large anti-friction reduction unit. It was 1500 hp., 350 r.p.m. The pinion bearing was 12 in. and the gear-shaft bearing was 17 in. The gear bearings were lubricated with 600-W oil. That unit has been working ever since, and there has been no trouble whatever.

On October 4 of this year we installed a new 28-in. mill, and the gear unit used is a 2000-hp. drive, 350 r.p.m. We felt it would be advisable to have the bearings lubricated separately from the gears and so worked out a system of lubricating the gears with 600-W and lubricating the bearings with a separate circulating-oil system. The oil pump is mounted on the gear shaft. It takes considerable time after starting for the bearings to become properly lubricated, and a lubricating system with a separate pump is preferable to a pump driven from the gear shaft. In any case a level should be provided in the bearing chambers for the oil. The bearings installed were large Timken bearings. They are run at high speeds, and it is very necessary that the lubricant be sent to the bearings at a good rate of feed and high pressure in order to keep them cool and clean at all times.

[2] Chief Chemist, Rock Island Lines, Chicago, Ill.

[3] Hodson Corporation, Chicago, Ill.

[4] Timken Roller Bearing Co., Canton, Ohio. Mem. A.S.M.E.

Where water conditions are encountered it is impossible to use oil. In those cases we use grease and force the grease through the closures so as to keep the water out. We are working out a special air seal now which we believe will keep the water out so that it will be possible to use oil.

LOUIS F. COFFIN.[5] The paper should spur on the adoption of the one-lubricant drive, and steel-mill operators should agree with the author that the death knell of the gear shield-bearing oil combination has been sounded for major mill drives. There are several important considerations that should shape the trend of this development. Accuracy of tooth contour and of bearing alignment must be given more attention so as actually to distribute the load over at least three-fourths of the tooth face instead of only one-fourth or one-half as is now too frequently the case. Gear and pinion material of sufficient hardness to give a long life is essential in order to justify the expense of the automatic one-lubricant oiling system. The author is quite optimistic when he states that "mechanical losses of oil are practically nil." Many manufacturers have much to accomplish in improved sealing devices, adequate oil pans, drain connections of ample size with proper vents, etc., before such drives may be considered oil tight. This fact is a serious present deterrent to more widespread use of oil for mill drives. Also in many installations, mill-water sprays are apt to strike the gear or pinion drives, and more protection from this contaminating influence is needed. The tendency toward using a heavier and heavier bodied oil seems to be in the wrong direction. A very heavy oil, say of 1500 to 2000 seconds viscosity at 100 deg. fahr., as also with a good gear lubricant and in most cases a good bearing lubricant, has the unfortunate property of not separating from water and dirt and scale as rapidly or as entirely under mill-operating conditions as an oil of 500 to 1200 seconds viscosity. Continued purity of the oil is essential and can be much more easily obtained with the latter oil. On account of this, mill main gear and pinion drives should be designed to use an oil within the latter ranges. The use of the pressure spray is of course to be considered the major means of lubricating gears in such drives, as well as the cascading baffles, but in certain slow-speed drives these, together with a bath, are often advisable. While reduced labor cost in operating such systems is generally to be expected, more intelligent supervision is, however, required.

### AUTHOR'S CLOSURE

In regard to what Mr. Franke has said, in many cases the type of grease used is dictated by the design of the bearings. For instance, on the roller bearings used on conveying tables we are using a lime-base grease of about No. 2 consistency, and in places where it is subject to severe heat conditions, a No. 3 grade grease. These are applied mostly by pressure fittings.

Due to the heat from the material passing over the rolls, the journal temperatures run as high as 200 deg. fahr. The ordinary type of lime-base grease which is adaptable for pressure feeding is not adaptable to those high temperatures because it turns to a thin fluid so easily, so we have reverted to a sponge type of grease or what might be called by the chemist a soda-soap grease, which has stood up well at these temperatures. In cement mills it has always been customary to use grease, and oftentimes the grease which has come in contact with the shaft becomes very severely charged or hard and caked; in other words, the oil content has been withdrawn and the grease has become useless. Correct heavy-bodied oils have improved the lubrication.

The same thing is true in a steel mill. Where there is considerable frictional heat and heat radiated from the material and where grease has been used, we have gone to very heavy cylinder oil and applied it mechanically in small amounts. And by using a cylinder oil that will stick on the journal shaft and by automatically controlling the rate of feed, we have improved the life of the bearing metal many times and lessened the cost.

From what Mr. Hodson has said, some may have gathered the impression from the paper that one oil is desirable for all types of equipment. That is not true. Nor is it true that we advocate the use of oil on all types of mills, regardless of the design or regardless of the speeds, temperatures, and pressures encountered. We manufacture a range of oils which we have found have worked out on various types of equipment, and where we have been in doubt as to the pinion pressures or tooth pressures that were to be encountered we have found it better to use as heavy-bodied a lubricant as could satisfactorily be circulated. Where the mechanical design is such that oil losses are not preventable and held within a range, we believe the use of a heavy-bodied grease is desirable. On the other hand, the advantages from the standpoint of a single lubricant we believe are very important.

On a large strip mill which is now being installed by the Wheeling Steel Company at Steubenville and which is to roll strip 60 in. wide, the pinions will be connected to a special system for handling a heavy-bodied oil under pressure. We do not feel that the reduction gears necessarily require an oil of this body, so that a separate system will be used for the lubrication of reduction gears and their bearings.

One of the first installations was at the Bethlehem Steel Company on the four Gautier mills which were put in four years ago. The 10,000-gal. oiling system used serves the Morgan pinions, reduction gears, and bevel gears. The Weirton Steel Company at Weirton, W. Va., has a 48-in. continuous wide-strip mill which is being lubricated by oil throughout for both the hot and cold mills. The Carnegie Steel Company at Duquesne is lubricating a 30-in. blooming-mill pinion with oil.

The Allegheny Steel Company has four stands of McIntosh-Hemphill cold-rolling mills, and the Bethlehem Steel at Sparrows Point has five mills operated on oil. One of the latter oil-lubricated mills is an 18-in. Morgan mill, the pinions of which have been oil lubricated for 10 years.

On the 14-in. skelp mill at Benwood, W. Va., the Timken roller bearings used on the edging rolls gave trouble when grease was used as a lubricant. This was remedied by piping up the roller bearings for oil. The Trumbull mill at Warren, Ohio, uses oil on the upper roller bearings and grease on the lower bearings.

[5] General Master Mechanic, Bethlehem Steel Company, Sparrows Point, Md. Mem. A.S.M.E.

# Progress in Management Engineering

## Contributed by the Management Division

Executive Committee: C. W. Lytle, *Chairman*, Geo. E. Hagemann, *Secretary*, Park T. Sowden, W. L. Conrad, Robert E. Newcomb, and W. R. Clark

As THE United States achieved the greatest yearly production of goods in 1926 and also the highest productivity per wage earner, that year has been called by some a "boom" year. On the other hand, there were none of the unfavorable symptoms such as inflated prices, so that it should more properly be considered a year of steadily increasing prosperity. This increase of prosperity began in the middle of 1924 and might have met a considerable decrease in 1927, judging from the usual length of business cycles. While 1927 has had some such indications, they have occurred temporarily and in spots, so that the year as a whole has been prosperous. In fact, commodity prices have fallen gradually, and there has been little strain on the money market. Instalment selling, while now very general, seems not to have increased excessively, and there are many who contend that as long as there is little unemployment it is a wholesome condition. Perhaps the real basis of this unusually long prosperity is the fact that wages have been very much higher relatively than prices, thus enabling wage earners to consume increasing quantities of goods. This in turn indicates that productivity has also continued to increase. Referring again to 1926, the bank savings of the United States increased a billion and a half dollars during that year, and the number of depositors increased nearly three million, so that a new high per capita saving rate of $211 was established for the country.

The Savings Bank Division of the American Bankers Association reports that more than half a million of the additional savers were depositors in school savings accounts. On the other hand, it is claimed in reliable quarters that this saving is no more than the natural compound-interest growth of earlier savings. Referring to our present $770 income per capita, and over $3000 wealth per capita, Dexter Kimball says,[1] "For the first time since the world began we are in touch with the abolition of poverty, through the tremendous output of our products." Regardless of what other factors may have contributed to the stabilization of this prosperity,[2] a large amount of credit was unquestionably due to the rank and file of American management, for competition has been increasingly keen and the margin of profit consequently declining. What is being called "the new competition" includes inter-industrial competition and inter-distributing competition as well as the old inter-commodity and international competition, for today we have silk competing with rayon, leather with artificial leather, copper with aluminum, etc., and furthermore manufacturers are taking over distributing functions, thereby competing with jobbers, and some retail stores are doing manufacturing.

### The European Situation

Our Government reports that the exports of the United States to other countries for the year ending June 30 were $4,986,000,000 against $4,283,000,000 for 1926. Imports totaled $4,253,000,000, leaving a favorable trade balance of $733,000,000. Exports of foodstuffs amount to $381,000,000 against $250,000,000 for 1926. Our store of gold increased $148,000,000. Wheat exports were two and one-half times greater than the year before.

Conditions in Europe have improved moderately, and their leaders are doing their best to gain the world markets. Foreign competition is therefore likely to affect us directly or indirectly to an ever-increasing degree. Mass production is being adopted as far as conditions will allow, and in both England and Germany there is a vast movement of regrouping and reorganizing. "Scientific Management in Great Britain,"[3] by L. Urwick, organizing secretary of Rowntree & Co. Ltd., describes the three periods in the growth of scientific management in Great Britain—the post-war period, followed by loss of interest in 1921 and a renewal of interest during the past year, the chief feature of which has been the formation of non-competitive groups interested in management research.

According to Edward A. Filene,[4] "Both the group-buying movement and mass production and distribution by large manufacturers have already advanced in Europe to a greater extent than many people realize. The chains of retail stores are progressing successfully in Germany and in England. As examples of successful modern mass manufacturing, there are the Morris car in England, the Citroën car in France, and the Batá shoe in Czechoslovakia, all of which are producing under mass organization and in mass quantities; but the trouble with Europe in large measure is that since the war it does not know how to buy its food or raw materials." Condemning the resort to tariff as a means of solving market problems, he concludes that "scientific mass production requires less and less tariff protection. The Chevrolet automobile or the Ford automobile requires no protection. Even with free trade it is inconceivable that any foreign automobiles could compete with these two in the United States markets. More than that, they could be produced very much more cheaply if the additional living cost that results from the tariff were removed, and therefore they could be exported and sold in still larger quantities than today." It is said that the name of Henry Ford is known in the remotest parts of Russia on account of the advent of the Fordson tractor.

The term "rationalization" as used in Germany is defined as: (*a*) increasing the profitableness of the industries by cutting down production cost of manufactured products to a minimum; (*b*) lowering sales prices so as to adapt them to the purchasing power of the consumers, and (*c*) making it easier for German products to compete in the world markets. They are also attempting some division of manufacturing or specialization on the part of individual plants and are establishing common sales bureaus to keep down overhead. In many ways they have gone beyond the United States in the matter of standardization.[5] On the other hand, with much less uniformity in the demands of European consumers, and with an oversupply of labor, the peculiar economic conditions of the United States are not likely to be attained.

Dr. Francesco Mauro, a leading industrialist of Italy, spent some time visiting American plants during the past year, and in summing up his impressions here, mentioned particularly the following items:

[1] "The Trend of Scientific Management," *Bulletin S.I.E.*, July, 1927.

[2] See "Stabilizing Prosperity," by Virgil Jordan, *Yale Review*, October, 1927.

[3] See *The Management Review*, October, 1927.

[4] New York *Times*, April 3, 1927.

[5] See article by E. J. Mehren in *Engineering News-Record*, August 5, 1927.

(a) High standard of living
(b) Freedom from radicalism
(c) Spirit of cooperation
(d) Amount of research.

He also paid high tribute to the influence of the late Frederick W. Taylor and Herbert Hoover. It is interesting to note the relative purchasing power of wages as reported by the National Industrial Conference Board. Taking the United States as 100 per cent, the purchasing power in Germany is 33 per cent, in Italy, 29 per cent, and in Great Britain, 57 per cent, and the average of 12 European countries is 41 per cent.

American industrialists and engineers have been welcomed as never before in Europe. As an expression of gratitude for courtesies shown the industrialists of Czechoslovakia, that government has awarded the Cross of Knight of the Order of the White Lion to five American engineers. Poland has also given the Commander's Cross of the Order of Poland to an American engineer who has served as an advisor for the past two years. In Geneva, Switzerland, there has been established an International Management Institute. Henry S. Dennison, the representative of the American Management Societies in Europe, reports that "there have been no revolutionary changes, but a considerably intensified carrying on of betterments not only in machines, but in the layout and arrangement of departments. Improvements in internal transportation facilities of every sort have been considerable during the past eighteen months." Edward Eyre Hunt, of our Department of Commerce, attended by invitation the World Economic Conference in Geneva last May and reports that "the emphasis on scientific management was very striking."[6] Forty-one countries were represented at the Fourth Congress of the International Chamber of Commerce in Stockholm last June, the U. S. having 162 accredited delegates headed by Owen D. Young. The Congress endorsed the conclusions[7] on rationalization and international industrial pools reached at Geneva by the Economic Conference. The main interest of the Congress centered on the subject of trade barriers. The retiring president, Sir Alan Anderson, called attention to the fact that there are 5,000,000 people out of work in Europe, as well as 20,000,000 others underemployed.

The third International Congress of Scientific Management was held in Rome during September and was attended by a number of American leaders. Their papers dealt with phases of "scientific organization of labor for industry, agriculture, public service, and domestic economy." In all, 176 memoranda were examined and resolutions were passed. Signor Mussolini made the closing address and asked the delegates to report that Italy was well ordered and was working out her own economic resurrection, for the progress of humanity and for peace between nations.

### Economics of Industry

It is significant that three engineers were invited this year to participate in a Conference of Economists here in the United States. Certainly the American industrialist has contributed much to the newer science of economics in the last few years. One of these new economic questions is that of thrift versus buying. Under present conditions business men are encouraging the public to buy as never before. Since current savings must be taken from current income, the value of the consumer's goods which can be currently purchased will, of course, be less by the amount of the current savings. One school of thought has therefore gone so far as seemingly to deprecate thrift. This is answered, however, by pointing out that savings may be invested in two different ways: first, in circulating capital—goods which are to go into finished goods—and second, in permanent capital to be used as a factor of production. If savings are invested in the former way, the permanent productive factors of the country are not increased. Such a use of savings does cause an oversupply of goods on the market. However, most savings get into permanent-capital goods which are not sold but used for further production and therefore constitute an ultimate demand for existing goods and are just as much a final market disposal of the existing or future market supply of goods as is the purchase of an equal amount of consumer's goods. This does not cause a future oversupply of goods. The increase in production resulting from extended permanent investment, if a stable price level is maintained, will furnish a sufficient increase in the national money income to enable investors to purchase the additional amount of goods. The equilibrium between supply and demand can therefore be maintained under conditions of an increasing production if all savings are invested in permanent-capital goods.[8]

Since primary forces are increasing the purchasing power of the masses, the maintenance of this fundamental situation is more important than to overpersuade in the matter of buying. If unemployment can be kept down and wages kept up, there will be a constancy of ever-increasing purchase power. Another writer points out[9] that business is trying so hard to get business that it is saddling itself with all sorts of expenses in trying to make people buy more goods, with the result that gross business has increased but net profit decreased. Here we have the problem of keeping down overhead. There is little question but that much can be saved in this field in the future, although an encouraging number of corporations have already brought their overhead to lower proportions. Consolidation of allied lines in order to use common resources is one of the ways of accomplishing this, but this has not always proved a sure means and overhead can be reduced in many ways without it.[10]

Ernest F. DuBrul, secretary of the National Machine Tool Builders Association, reports as the most outstanding development in that field the application of statistical methods to management. He says they are translating corporate accounts into dollars of equivalent purchasing power for different years, thereby giving executives real facts instead of the accounting delusions they have sometimes had. In this connection it is also noteworthy that statisticians are no longer content to plot nominal wages but are using curves made up to real wages, that is, the purchasing value of the wage.

Such economic problems as the best size of production lots are being studied everywhere. As many variables are involved, no practical formula has yet been developed.[11] The problem of selecting the best combination of equipment is also being studied and a formula developed some time ago has been simplified so as to permit wider use.[12]

A new danger of obsolescence has come through the continual discovery of new processes. The German process of making wood alcohol threatens present methods. Before the new process of making sugar from corn is in wide use it is announced that better sugar can be made from artichokes. The employer must be more alert than ever to avoid an enormous loss in equipment.

Hand-to-mouth buying or the use of small orders has brought about uncertainty and hardship on parts manufacturers, but

[6] See Conference Resolutions in July, 1927, Bulletin of the Taylor Society.
[7] *Engineering News-Record*, June 9, 1927, p. 951.

[8] See "Profits, Progress and Prosperity," by A. B. Adams.
[9] "Competition That Raises Prices," by Fayette R. Plumb.
[10] "How to Cut Overhead Expense," by J. H. Barber, in *Manufacturing Industries*, May, 1927.
[11] See paper by F. E. Raymond, A.S.M.E. Management Division, Management Division Quarterly, Jan., 1928.
[12] See paper by George Hagemann, A.S.M.E. Management Division Quarterly, Jan., 1928. Also two articles in Mechanical Engineering, September, 1927: "The Economics of Machine-Tool Replacement," by M. S. Curtis, and "Shop-Equipment Policies in Representative Plants," by L. C. Morrow.

it has in the main freed capital and prevented overstocking.[13] The Packard Motor Company has reduced inventories in the ratio of 1 to 12 as compared with three years ago. The Hudson Motor Car Company is reported to turn over its material inventory every 14 days, and the Loose-Wiles Company, which handles perishable goods, every 24 hours. As a result of this, the problem of least-cost purchasing quantities is being studied.[14]

### Business Cycles

All industrialists seem to have learned the importance of leveling off the peaks and valleys of business. Forecasting conditions and coordinating sales quotas with production schedules is making progress.[15] The Policy Holders Service Bureau of the Metropolitan Life Insurance Company receives reports from 250 industrial organizations each month for analyzing and charting.

### Plants

At least forty cities are advertising industrial sites. Some of these cities are selective in their approach, some are not. The employer must consider many things before he can attempt to find the one best combination of advantages. For brief statements of these principles see T. S. Rogers' two recent papers "Should You Lease, Buy, or Build a Plant?" *Manufacturing Industries*, September, 1927; and "Factors to Be Considered in Plant Location," Mechanical Engineering, November, 1927. A particularly fine example of locating a new plant was given by O. C. Spurling in the June, 1927, issue of the last-named journal.

The past year has seen examples of illumination using as high as 20 to 30 foot-candles as compared with 10 to 12 foot-candles which was formerly considered a maximum.

### Equipment

Not only has there been a great replacement of machinery due to improvements in design, but employers have been forced to seek every type of labor-saving device in order to offset the former supply of labor from immigration. Jigs and fixtures are being used in industries that never considered them necessary. Almost every skilled and semi-skilled worker today is supplied with some kind of special machine, tool, or fixture. Material-handling equipment, rapid-drying equipment, etc. are being installed in many processes where they have never been used before.

### Labor

The record of the year ended June 30, 1927, as regards the admission of aliens into this country shows an increase over the preceding year of somewhat more than 40,000. Yet the total for this year (538,000) is small as compared with the figures for 1913, so that the figures for 1927 are smaller than those for 1920, 1921, 1923, and 1924, but larger than those for 1922, 1925, and 1926.

Last spring a conference was called by the Philadelphia Labor Union and the Philadelphia Labor Institute, also with the cooperation of Central Labor College, of Philadelphia. Morris Llewellyn Cooke presided and later expressed the opinion that the growing interest of labor in the elimination of waste was one of the most encouraging developments. If carried into effect it may bring about an altogether new era. William Green, president of the A.F. of L., pledged the cooperation of union labor in every attempt to reduce waste, but declared that the resulting benefits should show proportionately in higher wages as well as in increased profits. G. L. Gardner, author of the new book on Foremanship,[16] also reports that foremen's organizations are studying waste-elimination methods more than ever before.

With the waning of prosperity conditions, manufacturers will face the difficult problem of stabilizing employment. Perhaps there is no more important problem than this. Prof. H. Feldman, of Dartmouth,[17] says, "Protect your sales program first. Analyze your markets, simplify lines, and reduce style hazard." This is important to labor as well as to capital. Reasonably steady, regular, and continuous employment creates a better state of mind, begets a feeling of confidence, and permits workers to make orderly planning for the future. L. F. Loree[18] describes a novel measure to meet this in what he calls an "elastic" work day. It consists in varying the length of the working day between eight and ten hours in accordance with the fluctuation and volume of business. He claims it could entirely obviate the necessity of layoff.

The increase in labor productivity has been most encouraging, although figures are not up to date. The Bureau of Labor Statistics, Department of Labor, has made a study of this from 1914 to 1925,[19] and reports the following percentage increases:

| | | | |
|---|---|---|---|
| Automobiles | 172 | Leather tanning | 26 |
| Boots and shoes | 6 | Paper and pulp | 34 |
| Cane-sugar refining | 28 | Petroleum refining | 83 |
| Cement manufacture | 61 | Rubber tires | 211 |
| Flour milling | 40 | Slaughtering and meat packing | 27 |
| Iron and steel | 59 | | |

The Bureau of Labor Statistics is also conducting an investigation into the efficiency of labor in various European countries. The assistant commissioner of the bureau was in Europe last summer and made studies in Great Britain, Belgium, France, Germany, Czechoslovakia, Austria, Switzerland, and Italy.

Over 500 industrial disputes have been handled by the Conciliation Service of the Department of Labor during the fiscal year ended June 30. These disputes affected either directly or indirectly half a million workers, and it is stated by the Director of Conciliation that more than 85 per cent of the cases handled by his office have resulted in satisfactory settlements.

The Travelers Insurance Company estimates that 27,000 American workmen will receive around $50,000,000 this year in benefits from group insurance.

### Standardization and Simplification

Standardization of design has made great headway. It has reduced the amount of work in the drafting room to a minimum and is doing much to keep down stock requirements. That standardization is opposed to specialization is called a fallacy[20] by W. S. Heyward, who claims it is often possible to specialize a standardized line and to make it distinctive.

Simplification, under the leadership of Herbert Hoover and the able assistance of R. M. Hudson of the Division of Simplified Practice, Department of Commerce, has spread far and wide. There are few industrial lines which are not now working in this direction. For example, the Norwich Pharmical Company has reduced the number of items produced from 4000 to 400. During the year it has been taken up by some foreign industrialists and is considered to be one of the great contributions of American Management.

### Conservation of Material

The Department of Commerce last April reported a reduction

[13] See "Building Cars Without a Stockroom," *Iron Age*, Mar. 17, 1927.

[14] See article by R. C. Davis in *Manufacturing Industries*, May, 1927.

[15] "Business Annals," by Thorpe and Mitchell, and "Business Cycles," by W. C. Mitchell, National Bureau of Economic Research, Inc., 474 West 24th Street, New York City.

[16] A .W. Shaw Co.

[17] "Regularization of Employment."

[18] *Industrial Management*, March, 1927.

[19] See Handbook of Labor Statistics.

[20] "Sales Administration."

in the use of raw rubber amounting to 22,000 tons over the preceding year, despite the fact that motor-car registration increased nearly 10 per cent. No doubt simplification has been accelerated by the tendency to buy for immediate needs only. An interesting method of controlling rejections, that is, defective production, is described by P. F. Cooper.[21]

### Marketing

The trend is toward intensive rather than extensive marketing. With this in view some national advertising is being placed in local newspapers instead of in magazines and other expensive mediums. Part of the advertising budget is being taken for research to ascertain what the consumer really wants. Professor Freeland of M.I.T. says, "Market evaluation must be based on inclination to buy as well as on capacity to buy." The study of distribution waste has gone on with particular attention to such practices as overselling, cancellation and returns, delays on deliveries, unethical credit practices, and discrimination. The difficulty in this problem is that it lies in the twilight zone between the manufacturer, the wholesaler, and the retailer. Functionalization has therefore penetrated this field, and the term "merchandizing"[22] is being used for the function between sales and production. That is, pricing, balancing of inventories with production schedules, and analyzing of advertising mediums is being solved by unprejudiced staff men. This is sometimes carried on under a sales planning department. Some leaders are warning industry not to go much further in "mortgaging future income." The importance of establishing prestige in business is being discussed.[23]

It has been claimed that buying materials on specification instead of by trade name will save the United States annually one billion dollars. The United States Bureau of Standards alone is said in this way to have saved 100 million a year on purchases. The new simplified invoice has been formally accepted by 12 associations and over 100 important business concerns, as well as by the Federal Specification Board. It is expected that this will come into general use in a short time. During the past five years the American Railway Association has reduced the entire carriers' payments on damages from 120 million dollars to 38 million.

### Clerical Operations

Many are taking steps to reduce the cost of office work. Simplified practice, better arrangement of desks, and the segregation of typists have done much. Typists and other operators of mechanical devices when placed in a group subconsciously fall into the rhythm of the group, and a slow operator entering the group will pick up a certain amount of speed. In addition, it is important that each clerk be assigned a full day's work, which is of course the result of job standardization or time and motion study.

### Safety

The survey of the Engineering Council has been published encompassing the experience records of about fourteen thousand companies and over one-fourth of the industrial work of the country. The figures show conclusively that a decreasing productivity is usually attended with a corresponding increase in the frequency and severity of accidents, and vice versa. The report includes numerous charts and shows trends in both accidents and production of 16 basic industries. "The rate of production per man-hour for the industrial groups studied," it says, "was 14.4 per cent higher in 1925 than in 1922. The rate of accident frequency per man-hour was 10.4 per cent lower in 1925 than in 1922. The rate of accident severity per man-hour was 2.5 per cent higher in 1925 than in 1922. Many industrial executives have not given to accident prevention that degree of attention and direction which its economic and humanitarian significance warrants. There is evidence to the effect that some industrial executives feel which because of compensation insurance carried, their responsibility has been met, hence they do not concern themselves with accident prevention. The initiation of accident prevention is as much a responsibility of the major executives as is the initiation of improvements in productivity."

The United States Steel Corporation has been a pioneer and leader in accident-prevention work. Not long ago it issued a report in which it was estimated that as a result of organized safety campaigns within the company over the period from 1912 to 1923, inclusive, more than 35,000 employees were saved from serious injury. The American Car and Foundry Company, another outstanding example in this field, spent approximately $1,000,000 in fourteen years for accident prevention, but estimates that it saved $2,700,000 in actual loss by this expenditure.

There is now going on an investigation of light, sight, and safety, from which much is expected.

### Traffic Devices

The American Engineering Council has a committee at work on street signs, signals, and markings. Over sixty leading cities have submitted data, and it is hoped to include 250 cities before they finish.

### Fatigue Elimination

Dr. A. T. Poffenberger, Department of Psychology, Columbia University, has carried on experiments in his laboratory which measure the amount of oxygen and the amount of carbon dioxide involved in certain work. He has found that the efficiency of the human body as a prime mover varies much as other prime movers. For instance, there is an optimum speed for every kind of work. By his methods he is able to determine the capacity for work and the energy cost of work increments. He points out that this type of measurement must precede the study of fatigue in its relation to ordinary output, but thinks it entirely feasible to approach that relationship later on. It is proposed to eventually make studies on many types of factory work under varying conditions of monotony, noise, light, etc. As similar studies are being made at the Kaiser Wilhelm Institute in Berlin, the problem of fatigue is at last being put upon a scientific basis.

Joseph A. Piacitelli describes[24] how the Barber Asphalt Company eliminated fatigue by rearrangement of machines and by better material handling. A 20 per cent reduc ion in the unit labor cost was the result. A similar reduction of 18.2 per cent in unit labor cost is described by W. C. Hasselhorn.[25]

A. B. Segur of Chicago says: "Nerve fatigue is apparently more important in industrial operations than muscle fatigue. On fast operations very few individuals are able to maintain the same operation for more than 15 seconds without making a mismovement. In industry, fatigue forces the operator to use a longer method of performing the operation, and therefore slows down the operation."

Dr. F. Hahn and S. F. Csohar, of F. B. Gilbreth, Inc., have been studying the subject. They have compared the motion of human arms with the motion of the pendulum, and from the

[21] *Manufacturing Industries*, May, 1927. See also three papers on "Control of Quality," A.S.M.E. Management Division Quarterly, Jan., 1928.

[22] E. A. Filene in "More Profits from Merchandising."

[23] "An Analysis of Prestige," by Ernest Urchs of The Steinway Piano Company, *The Music Trades*, June 25, 1927.

[24] *Manufacturing Industries*, July, 1927.

[25] Ibid., August, 1927.

pendulum law point out that either to accelerate or retard the natural motion requires an extra effort, causing fatigue. They say there is superfluous fatigue if a wrong path is used or if the distribution of time along the path does not correspond with a simple harmonic motion. Undoubtedly the Gilbreth micromotion method which uses a motion-picture film is well adapted to this study, and may be expected to develop definite laws. Dr. D. A. Laird is conducting research on the noises of cities. So far it is a matter of measurement rather than of prevention, but there seem to be great possibilities in what may follow. Dr. Laird declares that noise exceeding 35 units in his scale of measurement actually increases the blood pressure of human beings exposed to it. Note also the work of Prof. H. J. Spooner of London.[26]

Vacations with pay[27] are becoming the rule and are doing much to stimulate the loyalty of employees as well as allowing them a change without financial worry.

### Incentives

The National Metal Trades Association is making an extensive study of wage incentives among their companies. Interest in incentives seems to be gaining, and L. P. Alford, editor of *Manufacturing Industries*, has observed that industries having the highest productivity also have the highest percentage of workers on some incentive plan.

Sales executives are trying incentives of all kinds, and find that by a few changes in terms the experience developed in the factory is applicable to their field. The cutting of piece rates or commission rates has become uncommon, and the response to such incentives is therefore more wholehearted than ever before.

### Research

There has never been so much importance put upon research as at present. The Western Electric Company maintains a staff of 2000 for this purpose, with an annual expenditure of more than 8 million dollars. General Electric and General Motors each spend over a million annually.[28] Concerns which cannot afford these large expenditures are either working through their trade organizations or through the facilities of universities. The American Gas Association has a comprehensive program. Systematic use of research during the last five years is believed by the Copper and Brass Research Association to have been largely responsible for doubling the consumption of copper during that period. In some cases the trade organizations have raised endowments and have used them to build and maintain laboratories on university grounds. For instance, the Tanners' Council of America and the Lithographic Technical Foundation have done this at the University of Cincinnati. The precedent of the University of Toronto retaining the patent rights from basic discoveries, is being followed in several cases. There has recently been formed a Druggists' Research Bureau, to act as a national clearing house for obtaining facts necessary to the welfare and success of the drug industry. All this is partially a result of the tendency to abandon the rigid secrecy which companies have so frequently thought necessary.

One of the most important and significant developments in this direction has been the formation of a research organization by the U. S. Steel Corporation. Here the subsidiary companies carried on a good deal of valuable though uncoordinated research and invention work for years, but the parent company kept aloof. The new body has been given a particularly high standing in the Corporation by a provision under which it is made to report to the Finance Committee, the highest governing board in the Corporation, and by having such men as Professor Millikan and Professor Johnston to direct its destinies.

### Miscellaneous Application of Management Principles

There has been some reorganization of governmental departments. For instance, the U.S. Patent Office has been studied by two engineers and a sub-committee. The report contains 108 recommendations which would considerably simplify practice.

Department stores are beginning to hire management engineers and are doing a great deal to eliminate waste. In one New York store the cash clerks have been studied by micromotion and their work standardized in the "one best way." The psychiatrist is being consulted in the matter of selecting clerks, and it is said by executives that this has proved profitable. Chain stores are succeeding by leaps and bounds, and they are doing this by the same principles used in mass production.

Agriculture is turning to research in the matter of mechanical equipment. A survey recently made includes over 400 suggestions for research. The Department of Agriculture expects to follow these up. Under the guidance of Mrs. L. M. Gilbreth, a series of lectures have been delivered at Columbia University, in which engineers have described the possible applications of management methods to the home.[29] Interest was keen. Interest was also evinced in this subject in the conferences held in Europe in the past summer. Similar reports come from prisons, hospitals, and schools at which various engineering methods are beginning to find adaptation.

### Management Societies

The New England Council, composed of eight men appointed by the governor of each state, 48 men in all, assembled about 2000 men at Springfield, Mass., in November to discuss management in manufacturing.

The American Management Association has established an Institute of Management, membership in which is elective and based on achievement in management research. The very large number of company and research sustaining members which this association has secured indicates a greater interest on the part of high executives than has ever been shown before. The Management Division, A.S.M.E., has prepared a bibliography which is more comprehensive than any heretofore published.

L. P. Alford's paper on the "Laws of Management," mentioned last year, was the first to receive the Melville Award.[30]

### Costs

Competition is forcing cost finding into all phases of manufacturing. For instance, the Utica Knitting Mills studied their factory heating and found that by revamping their old system they could save $17,000 annually. Similarly there is a renewed effort to reduce the cost of power. Hubert Collins reports four instances in which savings have been accomplished amounting to 23, 19, 13.5, and 11.8 per cent over former costs.[31]

The spread of standard cost methods has continued and is being fostered by trade associations. Manufacturers are studying labor costs as compared with carrying charges of mill equipment. The cost of obsolescence is becoming of particular interest. Budget control is almost universally in use.

[26] *S.I.E. Bulletin*, Sept., 1927.

[27] "Vacations for Industrial Workers," published by the Industrial Relations Counsellors, Inc.

[28] See National Research Council Report, *Iron Age*, Sept. 1, 1927, p. 567.

[29] "The Home Maker and Her Job," by L. M. Gilbreth, D. Appleton & Co., "Homemaking as a Center for Research," Bureau of Publications, Teachers College, Columbia University.

[30] See Mechanical Engineering, April, 1927.

[31] *Manufacturing Industries*, August, 1927.

### Education

Courses in industrial engineering have not increased in number as rapidly as have courses in business administration. There is, however, an increasing tendency to offer options in management to engineering students. Rutgers University, New Brunswick, N. J., has recently offered a new four-year course in industrial engineering. It is an option in the Department of Mechanical Engineering and leads to the degree of B.Sc. in M.E.

The American Council on Education is using its influence to have schools make more accurate records of conditions in all types of occupations in order to aid employers in selecting material for employment.

Trade associations are raising endowment funds for private institutions conducting courses in their particular fields. As an instance of this, the United Typothetae of America has established an endowment of $225,000 at Carnegie Institute. The Association of Cooperative Colleges held its second annual convention in Philadelphia last June and was more largely attended by employers than by educators. This is considered a very encouraging aspect. The convention proceedings may be purchased from the Secretary.[32]

### Industrial Museums

New York City has assigned to the Museums of the Peaceful Arts seven city blocks on the site of the Jerome Reservoir. This movement was started nearly 20 years ago by some of New York's public-spirited citizens: Judge Gary, Jacob Schiff, George F. Kunz, and Henry R. Towne. Calvin W. Rice was elected secretary, and Dr. Kunz, president.

At the time of Mr. Towne's death he left his residuary estate, amounting to approximately two and one-half million dollars, for this project, provided it should be successfully promoted. It would seem now with the recognition by the City of New York that the Towne bequest would become available.

Other movements, such as the National Museum of Industry, which was planned to be affiliated with the Smithsonian Institution in Washington, the Museum in Chicago, the original bequest for which, three million dollars, was given by Julius Rosenwald, supplemented by five million dollars by the city of Chicago, and the old building of fine arts occupied during the World's Fair, have been started since the original movement for the Museum of Peaceful Arts. But it is stated that they can all be made a national movement for the benefit of the whole nation as a part of the education and inspiration of all those engaged in industry.

Similar museums are proposed in Pittsburgh and in Philadelphia. The national engineering societies have indorsed both the movement for the Museum of Peaceful Arts and the National Museum of Industry, and all engineers generally should become identified with this movement as a direct contribution of the engineering profession to industry.

The Museums of the Peaceful Arts now occupy temporary headquarters at the *Scientific American* Building, 24 West 40th Street, New York, where a start has been made in organizing a great industrial technical museum for the city of New York.

### Management Week

The subject this year was Management's Part in Maintaining Prosperity. Cecil Ashdown, vice-president of Remington-Rand Company, was chairman of the National Committee, and R. M. Hudson, of the Division of Simplified Practice, was secretary. The movement has become one of national interest and has secured the support of many non-engineering organizations.

### Waste Elimination

While all of the foregoing indicates encouraging progress in the general elimination of waste, there is still a great deal which has not been done. The American Society for Thrift estimates our annual waste of coal at 750 million tons, of water at 50 million horsepower, of oil at one billion barrels, of lumber at 5 billion cubic feet. The Department of Commerce estimates that our annual waste in transportation equals one-half billion dollars, and says the shipper is largely responsible.

While materials handling has been studied more than ever, it is still thought that one billion dollars could be saved annually on payrolls by better use of present equipment and arrangement.

There were 135,000 commercial failures from 1920 to 1926-1927, inclusive, with total liabilities of $3,500,000,000. Seventy per cent of all the failures in 1924–25 and 25–26, occurred in the trading groups, and their share of the total liabilities increased from $37^1/_4$ per cent in 1924 to 49 per cent in 1926. Bradstreet's analysis of causes of failures during the years 1922 to 1926, inclusive, gives "incompetence" as the reason for 35 per cent of the cases, and "lack of capital" for 33 per cent more. The other 27 per cent are scattered among "inexperience," "extravagance," "speculation," "fraud," etc.

Finally, although most of the bankers and leading financial men are far from pessimistic, they are advising their correspondents and clients to get their affairs in better liquid condition for the spring of 1928. As far as the engineer is concerned, his influence has definitely increased and his doings are becoming desirable news for publication. The owner of business is now less apt to confuse the mechanisms of management with the spirit of management, and thus the reaction against so-called "efficiency" is vanishing.

Chas. W. Lytle, *Chairman.*

[32] C. W. Lytle, New York University, University Heights, New York City.

# Production-Control Methods in the Rubber Industry

## A Statement of the System Employed in the Akron Plants of the Goodyear Tire & Rubber Co.

By F. B. CALHOUN,[1] AKRON, OHIO

A FEW years ago the rubber industry was expanding very rapidly. This was due primarily to artificial stimulation in industry caused by the conditions existing shortly before and during the World War. As a result, the most important economic matter of all, "the production of maximum output with present equipment and facilities at a minimum cost," perhaps was not given sufficient consideration. Subsequent developments were inaccurate records, excessive raw-material inventories, poor turnover of in-process materials, excessive material wastes, and an exceedingly high rate of labor turnover.

It should be borne in mind that the rubber industry is seasonal, subject to violent fluctuations in the price of raw materials and sales demands. The conditions above cited led the Goodyear Tire & Rubber Company to organize methods to meet this situation in the most satisfactory manner possible.

The first step was to segregate the various functions essential to production control. These included the ordering and control of productive materials, the issuance of schedules, the dispatching of materials through the different processes, the stocking of raw and finished materials, transportation, and shipping.

It should be understood that these functions were actually in effect, but so decentralized or distributed between the various departments, that the management had no instrument which would permit efficient control. The selection and training of proper personnel, qualified to handle this work, presented quite a problem in itself, due to the fact that personnel experienced in control work was not available.

### Materials Control

The function of the production-control division at the present time begins with the ordering of materials required to produce the various products manufactured. A yearly estimate is developed by the sales department, outlining probable requirements on each product manufactured by the company. This program is carefully analyzed by the management. When approved, it provides the basis for additional capacities and plant facilities where necessary. If any changes in design or equipment are contemplated the yearly estimate is given to the consulting engineer, who formulates commitments, and in turn works out the program.

This estimate is revised monthly to meet changing conditions in sales demands. This revised estimate is broken down into its component parts by the production-control division. Occasionally sales increases on certain products may largely exceed previous plans and require greater floor space, more equipment, more men, and more materials. Likewise, a decrease in sales may mean that curtailment must be made. Consequently, a definite tentative manufacturing schedule, broken down into specific quantities on each item, is compiled from market reports. It is then delivered to the production-control division. These estimates are submitted thirty days in advance of going into effect. They cover periods varying from thirty days to six months, depending upon the product. The factory decides whether the tentative program is possible.

### Ordering Materials

This schedule forms the basis for releases and for planning the requisitions of materials which are not ordered on a contract basis, and on which quick shipments can be secured. The production-control division regulates the inventory on all productive materials.

From the tentative production schedule, a purchasing budget of materials is prepared. This is sent to the assistant comptroller. When approved it goes to the purchasing department as an authorization to fill the requisitions which will be placed by the production control division. The purchase budget shows the quantities of materials on hand, en route, and on order, and the coming month's requirements. In addition, the definite needs for two months ahead and the probable needs for four to six months ahead are listed. The probable inventory is also calculated for four to six months in advance. These data form the basis for contracts for materials which can be most advantageously purchased on commitments and released on shipping orders.

Purchase requisitions are made out after these budgets have been approved. The backs of the requisitions are ruled for purchasing records. In our attempt to synchronize incoming materials with consumption we are, in some cases, scheduling the plants of our vendors. To facilitate this plan further we are gradually revising layouts so that incoming materials may be dispatched direct from the receiving platform and stocked adjacent to the point of consumption. This program has enabled us to reduce storeroom space and handling charges.

### Production Schedules

Daily, weekly, bi-weekly or monthly, depending upon the product, manufacturing tickets are made up within the limits of previous estimates, and forwarded through managerial channels to the production-control division. These tickets are first checked to see that all material and equipment are available for producing. This procedure is very important in the control of in-process material because if a definitely prearranged schedule is interrupted at any point of process, due to a shortage of material or equipment, surplus inventories will result.

All products are classified as follows: First, standard stock. Under this classification are all products that are sold in sufficient quantity to justify stocking both at Akron and in the branches. Second, Akron stock. Under this classification are all products that are sold in sufficient quantity to justify a stock at Akron only. Third, special manufacture. Under this classification are products that are made to order only, such as customer's brands, conveyor belting, hand-built hose, etc.

When the requirements are received by the central control division, they are broken down into daily machine schedules. In the compilation of these schedules, the following points are considered; First, economical grouping in order to obtain maximum machine capacities and minimum waste of material. Second, relative importance of orders on hand. An emergency order system has been found necessary because of the policy of low

[1] Manager, Production-Control Division, Goodyear Tire & Rubber Co., Akron, Ohio.

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inventories in all lines of industry. With the flexibility which has been created in labor and equipment, emergency orders are handled without confusion.

### Labor Control

Labor requirements are studied in a thorough manner to facilitate carrying out the production program in the most effective manner. The labor department is called upon when the ticket is received to supply trained men in numbers sufficient to handle the production. As such men are not always immediately available, the labor training department must have time to engage and train them when a larger force is to be put on, before the ticket becomes effective. Likewise, when reductions are made, the labor department must be informed so that it will stop engaging men to be trained. In such cases, transfers of employees to other departments that are active can be made, and hardships to workers avoided.

The control organization confers with the production and labor training foremen relative to the type of work and the number needed. Requisitions for labor and daily labor conditions reports are made out by production control for the various production departments.

### Importance of Thinking in Production Cycles

The personnel working on basic schedules must be trained and developed to think in terms of production cycles. If the central control men do not do this, one department will not be properly synchronized with another.

All products, either standard or special, when placed on schedule, are allotted a definite time for completion. Occasionally normal production time limits must be extended due to a sudden influx of emergency and special orders. When this occasion arises, the merchandise distribution department is promptly notified in order that the sales department may be informed that it is necessary for the branch or customer to wait longer than usual on the particular product affected.

In order correctly to synchronize the flow of material through the plant, it is necessary for all machines to work to a time standard, scientifically determined. Therefore, all work is scheduled by machine minutes. The chart used in breaking down orders into minutes is based on piecework rates.

### Workers' Interests Guarded

In order to eliminate discontent on the part of the pieceworker, earnings over an 8-hour period must be considered at the time the schedules are written. Each schedule or order received from the merchandise distribution department is broken down into production minutes and a chart is posted at intervals during the day showing work ahead of each group of machines. By the use of this chart, a decision is reached as to the number of machines and working shifts required.

### Dispatching of Work

A mathematical breakdown of incoming orders is not difficult, but a daily schedule properly coordinating equipment, labor, and material, and synchronizing one department with another is a task of unusual difficulty. It has heretofore been found necessary to station at different control points throughout the plant, a dispatching organization to provide shift schedules based on local conditions and assign work in accordance with the predetermined schedule. The dispatching organization must keep the schedule men, located in central control, informed in regard to back schedule, breakdowns, inexperienced labor, and various other kinds of essential information.

The centralized control of all schedules and the assignment of work to machines throughout the plant is the only method by which production can be regulated to assure harmony and uniform operating conditions.

In the tire departments where certain machines are assigned indefinitely to a specific construction, the dispatching function is mainly one of keeping process inventories properly in balance. However, in the case of certain mechanical-goods departments, where a job may represent only a few minutes' work to a machine, the task of keeping the machines properly supplied with work, without delays, is rather difficult.

To assist in this work, the dispatcher is provided with job assignment orders, serially numbered, outlining the specification of the particular product. Dispatch boards have been installed and these orders are so arranged that the condition of the department is semi-graphically outlined. By this method, the production-control organization dispatches material through all operations in production and into the finished stock and shipping departments. The job assignment order is the authority to manufacture all products and its design varies with departments.

These assignments are typewritten and represent the largest amount of product that can be economically routed through the different departments without producing congestion, but still keeping all machines busy and providing an orderly sequence of work. The assembly of the assignment order is composed of as many copies and colors as are required for assignment of work to each individual operation, for maintaining the records necessary to intelligent dispatching, and for the rendering of the operator's or crew's time.

In the control of the wrapped-hose department, which is representative of other mechanical-goods departments, the assignment order consists of six copies; first—special white (for cost department), second—white (for stock cutting operation), third—blue (for tubing operation), fourth—yellow (for building operation), fifth—salmon (for finishing operations), sixth—pink (for finishing and assembling operations).

Each copy is sent to the succeeding operation after the previous operation has been performed and serves as authority to produce the quantity specified. Completing the operation, the supervisor places on the face of the copy, the name of the operator who did the work, the quantity, and the time required. This form is next returned to the control station. Here the clerk inserts the piecework rates and extends them to show the labor cost. This sheet, which takes the place of the traditional time card, goes to the accounting department.

### Cost Data and Time-Keeping

The labor costs are summarized from the detailed sheets, transcribed to a master sheet, and then identified by factory order, specification, and operation numbers. As the labor is charged directly against each operation and product, this system enables the accounting department to determine just what each product is costing. In this way the products which are failing to produce a profit may be gradually eliminated and efforts concentrated on lines which make a more satisfactory return. The payroll is likewise made up from these sheets.

The combining of timekeeping and production records has reduced possibilities for errors and has eliminated much duplication in clerical work. The rendering of time and the supplying of basic cost data is a dispatching function. Generally, the making out of all time is now being handled by the production-control department.

After the different copies of the assignment order have served their purpose in dispatching material through the production departments, three copies of this order accompany the material to the stock room. One copy is receipted and returned to the production-control department where it is filed with the manufacturing order for reference on deliveries, in case any question

arises after the material is shipped. Another copy goes to finished product control which in turn notifies the merchandise distribution department that the product is available for shipment. The latter department then releases the shipping copies of the order. The third copy, in some cases only, is retained by the stock room for use in identifying material.

### Daily Reports

Daily production reports are made by each plant, summarized from the records of all shifts in each department. These reports cover the work scheduled for each line of product, the amount turned out, the overrun or shortage, the losses and their causes, the number of workers in each department, number of absentees and a summary of the total schedule, the actual production and the amount over or under the schedule. Daily condition reports are also turned in by the supervisors stating the causes of any difficulty experienced.

A monthly report summarizes these factors in all departments of each plant. Items requiring attention are pointed out and desirable changes in equipment and methods are suggested.

### Organization

TABLE 1 SUMMARY OF CLASSIFICATION OF PRODUCTION-CONTROL PERSONNEL

| Classification | Number employed Plant No. 1 | Plant No. 2 |
|---|---|---|
| 1 Manager | 1 | 1 |
| 2 Foremen | 3 | 3 |
| 3 Head supervisors | 6 | 6 |
| 4 Central control | 7 | 5 |
| 5 Chief dispatchers | 15 | 14 |
| 6 Senior dispatchers | 50 | 41 |
| 7 Junior dispatchers | 58 | 39 |
| 8 Stock dispatchers | 12 | 13 |
| 9 Scalemen | 7 | 14 |
| 10 Secretarial, clerical, and checkers | 48 | 33 |
| 11 Clerical and messenger | 1 | 2 |
| Present department average | 200 | 156 |
| Total in plant | 217 | 171 |
| Total in Plant No. 1 | | 217 |
| Total in Plant No. 2 | | 171 |
| Assistant superintendent and manager | | 2 |
| Total | | 390 |

TABLE 2 CLASSIFICATION OF DUTIES OF PRODUCTION-CONTROL PERSONNEL—PLANTS NOS. 1 AND 2

| | |
|---|---|
| Manager | In charge of plant functions and personnel. |
| Foremen | In charge of division. |
| Head supervisors | In charge of control functions and personnel, several departments. |
| Plant Nos. 1 and 2—Central Control | Contact, master schedules, and materials control. |
| Chief dispatcher | In charge of station—all shifts. |
| Senior dispatcher | In charge of shift—local schedules and dispatching. |
| Junior dispatcher | Floor dispatching and timekeeping. |
| Stockkeeper | Handling and dispatching stock in and out of storage points. |
| Scalemen | Weighers. |
| Secretary and clerical | Typists, clerical work, and checkers. |
| Clerical and messenger | Clerical work and messenger service. |

### Wage Incentive Plan

Our experience on incentive plans of wage payment is somewhat limited. The establishment of piecework rates or incentive plans of wage payment has not fallen within the scope of production-control work at the Goodyear Tire & Rubber Co. It is economically correct that the operator of exceptional merit shall receive an exceptional day's pay, the average man an average day's pay, and the poor man a poor day's pay. The piecework method of wage payment recognizes this fundamental principle. The management of the Goodyear Tire & Rubber Co. has not thought it advisable as yet, other than in an experimental way, to install any incentive plans of wage payment.

However, the mechanism necessary to operate any plan of wage payment successfully is now established. Correct information for control, costing, and wage payment has been provided. The possibility and temptation of cheating by operators has been eliminated. The management tells the operator what he has produced and renders all time, rather than the reverse practice. Before wage incentives were considered in an experimental way it was believed that delays and hindrances attributed to managerial causes must be reduced to a minimum, in fairness to the operator. We believe this condition has been created in a satisfactory manner. The possibility of increasing plant efficiency through incentive stimulants becomes correspondingly less where scientific schedules and proper standards for execution are set and enforced by the management.

These remarks are made with the understanding that a well-developed plan of scientific management must include incentive plans of wage payment and as previously stated, the Goodyear management is now working experimentally on this problem based on quantity and quality.

One of our most important operations is final inspection. A form of incentive plan was introduced to see whether or not it would have any effect on quality. The basis of the incentive plan was an allowance of 50 per cent for quality of a certain standard, and 50 per cent for quantity. This system was in operation but a short time when it proved conclusively that the quality of the product had depreciated. Immediately the basis of the payment was changed to 90 per cent for quality and 10 per cent for quantity. The quality of inspection on this operation is at a higher point today than it ever has been. This particular plan has rested upon its merits and has proved successful.

### Summary

To summarize briefly, an analysis and classification of the steps required in manufacturing has been made. Departments have been fully organized to handle each type of work that is to be done. A close relationship has been developed between these departments so that they work together. Output is based upon market demand through direct contact between sales and production departments.

A logical, and as far as possible, automatic procedure has been established to put orders in shape for rapid manufacturing and to have men, equipment, and materials ready to handle production on a definite, smooth schedule. Production control, or the responsibility for the scheduling of work and the coordination of men, equipment, and materials to do it, has been definitely separated from actual production, or the doing of the work. Local units keep in constant touch with the progress of work and see that schedules are lived up to every hour of the twenty-four Inventories and work-in-process have been radically reduced.

Finished stocks are kept at an economical level, but distributing branches are amply served and shipping dates are met.

Employment has been stabilized. Labor has increased in efficiency. Developments are still producing equally remarkable results, and the management has demonstrated beyond a doubt that production control in continuous process industries can be made a complete success.

## Discussion

W. S. Richardson.[2] Before one can really enter into a discussion of any particular application of scientific management in an industry, consideration must be given to the peculiarities encountered within that industry. The practices incidental to the application of the management plan can then be examined and the method of surmounting the obstacles be observed.

[2] Manager Planning Department, B. F. Goodrich Rubber Co., Akron, O.

In the first place, production control reduced to its least common factor, undoubtedly is that function in organization whose aim is to produce a given quantity of product in a given time with a given quantity of raw material. In order to be able to accomplish this in the rubber industry, particularly on products known as mechanical rubber goods, wherein the demand rises and falls in rapid cycles in an industry which requires a high degree of technical skill and a great variety of raw material, the following obstacles will be encountered:

1 Shortage or excess of raw material required in producing a given quantity of product in a given time
2 Rapid variation in the demand for trained labor to meet and balance the rapid changes in the production rate, particularly on mechanical rubber goods
3 Variation in the production rate due to defective material prior to and subsequent to process
4 Variation in the production rate, due to equipment breakdown
5 Variation in the output per man.

Let us examine the first obstacle, material supply, and see how, in the instance presented, the matter is handled. The production-control department has a knowledge of the articles and quantities to be manufactured thirty days to six months ahead of the actual production period. This information is forecasted by the sales department and insofar as mechanical rubber goods are concerned, is the only instance within the industry that such a set-up has been effected. It is the backbone of effectiveness for production control, and from any angle is a highly commendable practice, reflecting a very well organized plan of merchandise distribution which carries the product direct to the consumer.

With this knowledge a breakdown into material requirement is comparatively simple. But to supplement this we find that the production control department has responsibility for plant raw-material inventory. This means that while it must see that the purchasing department procures sufficient raw material at the required time, it must also see that it does not procure too much. This is accomplished by means of purchase releases issued by the production-control department to the purchasing department, indicating the quantity and the time at which any material is to be brought into the plant. This is a novel idea as applied to the rubber industry.

The second obstacle is the supply of labor involved in an industry with rapid changes in the production requirements. Here the production control has a real weapon in the shape of a supply of super-labor which can be used at its discretion to maintain the required labor in uniform balance to meet a predetermined rate of production, and also to absorb the shock incidental to rapid increases or decreases in the output required by sales. This is an extremely happy plan. It merits full consideration in the avoidance of costly labor turnover in a large plant manufacturing a diversified product, which has widespread use and requires rapid delivery after the actual placing of an order.

The third obstacle is always present in the rubber industry; namely, variation in production rate due to defective raw material or defective product. Here it appears that the production-control department at the Goodyear plants has made no mention of any facts which would tend to show that this had been overcome. The industry would certainly welcome any foolproof safeguard against this contingency.

Nor do we find any solution for overcoming the liability of equipment breakdown, although the flexible labor supply would in most instances permit average breakdown loss to be rapidly discounted.

Variation in the output per man, will, in the absence of a wage-incentive plan, generally be found to rest at a fairly uniform level. To discount any variation, the Goodyear production control has two weapons—first, the flexible supply of trained labor; second, the data it can accumulate incidental to its rendering of output per man to the timekeeping and cost departments which permit it to put into process only such quantities as the records indicate can be accomplished; third, its network of dispatchers who can quickly reflect any condition in either direction that may tend to build up the in-process inventory.

In summary, it can be said that from all angles, the fundamentals underlying the plan of production control as established at the Goodyear Tire & Rubber Co. have much to commend them in any continuous process industry. From the point of view of a company in a similar line of product, facing the same problems, one cannot do less than to state that much of value can be gained from giving serious consideration to the adoption of methods as fitting to the needs of the times as those practiced at Goodyear.

The writer's company has been working in this same direction for the past two years. While the work has not progressed to the degree current at Goodyear, more territory is being embraced. Side by side with production control, wage payment incentive plans are being developed, and in addition, a plan to govern the consumption of raw material within the limits of the amounts used in costs, much the same as labor is governed. This function which has been separated from the direct production forces is called material control. It embraces control of all the elements of waste, both seen and unseen, occurring along the production route. It is needed in the rubber industry in the control of plant and in-process inventory as much as is control of the rate of output, for an excess use of any material beyond the understood limits will do much to make unsteady and ineffective other controls that have been set up.

The Author. Problems peculiar to the rubber industry, which are mentioned in Mr. Richardson's discussion of my paper, will no doubt continue so long as present conditions and processes of rubber manufacturing exist. The solution is largely one of organizing methods to meet these various irregularities in the most effective and economical manner possible.

Methods which are now used at Goodyear in overcoming these obstacles seem to be understood with the exception of the manner in which we handle machine breakdowns, defective materials, variations in labor, etc.

In addition to disruption of previous estimates and plans caused by changed conditions in the sales field, provisions have also been made to safeguard against excessive waste and local plant irregularities. These irregularities are caused mainly by replacement of defective material, changes in specifications, machine breakdowns, damaged auxiliary equipment (such as molds, cores, etc.), experimental and emergency orders, slow and fast labor, absentees, over or under running of schedules, and other items too numerous to mention. The efficient accomplishment of plans to cope successfully with these disturbing factors, which oftentimes cannot be foreseen or planned in advance, must be immediately regulated by adjustments of schedules and labor.

A suitable mechanism of control, sufficiently flexible to meet these constant changes, has been provided to assist in insuring proper turnovers and desired deliveries of finished product. This function and responsibility is handled by a local combination scheduling and dispatching organization which reassigns work in the proper sequence to suit the needs and means available at each operation in the particular circle involved.

In connection with the controls which have been set up at Goodyear to smooth out variables and irregularities, the management is also constantly applying corrective measures and improvements which tend to reduce disruptions and the resultant waste to a minimum.

# Coordinating Wage Incentives and Production Control

## A Short Account of the Various Methods That Have Been Tried in the East Pittsburgh Works of the Westinghouse Electric & Manufacturing Company, Together with a Description of the Plan Finally Adopted and Now in Use

By D. B. CHARTERS,[1] EAST PITTSBURGH, PA.

THE forty-two years that the Westinghouse Electric & Manufacturing Company has been in existence have afforded that company considerable time in which to try most of the plans advocated for increasing production by means of wage incentives, and it is the purpose of this paper to explain briefly the plan which is now in use as a result of this experience and to tell how it can be applied to other than productive labor in order to obtain the condition suggested by the subject of this paper.

The plan developed is known as the Standard-Time System of Wage Payment and has become the adopted plan in our work.

The fundamentals of the Standard-Time System are a day rate, a standard-time rate, and a time allowance.

The day rate is considered as being a fair rate for a certain class of work in a community when paid for on a day-work basis.

The standard-time rate is a certain percentage higher than the day rate, and is offered as an incentive to perform the work within the time allowance. When speaking of a "class" of work, reference is to the Westinghouse plan of job classification wherein all jobs in the shop are placed in one of five classifications, namely, unskilled, repetition-routine, semi-skilled, skilled, and highly skilled.

A range of rates, both day-work and standard-time, is assigned to each class of work and is recorded on what is known as the "key sheet." This sheet shows the maximum and minimum rates that may be paid for all classes of work, and is used by the Employment Department when hiring help.

The standard time or time allowance for a given operation is the time which can be met by an average worker working normally under average conditions, and is obtained by means of a time study.

A time study is a study of the detail operations required to complete a certain job, and the recording of the time in such a manner that comparisons and selections may be made. A study should only be taken when conditions are satisfactory and the methods standard as to motions and their sequence.

Whenever possible a formula is compiled from the time-study data, and for any given operation will cover all conditions likely to be encountered. Consistency is one of the most important advantages of the formula, or perhaps it could be better stated were we to say that the formula tends to eliminate inconsistencies.

### Principles of the Standard-Time System

A standard-time allowance is established on each operation or job. When the time taken to perform the work is equal to or less than the time allowed, the operator is *paid for the time allowed* at his standard-time rate, which is, as already stated, a certain percentage higher than his hourly day rate. When the time taken is *greater* than the time allowed, the worker is *paid for the time taken* at his day rate. From this procedure it is seen that the worker is guaranteed his hourly day rate.

A decided advantage in connection with the application of the Standard-Time System is that it affords a means for checking the efficiency of each worker. This is accomplished by means of what we call a "fall down" card and a performance chart. The advantages to be gained by the system depend largely upon the proper handling of the "fall downs." By "fall downs" are meant those cases where the worker does not complete the work within the time allowed.

The procedure that has been adopted as standard for handling "fall downs" is as follows: When time slips are turned over to the time clerk, he promptly extends the time, and in all cases where the worker has failed to meet standard time, he makes out a "fall down" card and forwards it to the time-study man who interviews the worker in order to determine the reason for the fall down, correcting all cases where the failure was due to causes over which the Time-Study Department has control. After making the proper notations, the "fall down" card is sent to the foreman, and after receiving his comments and signature, it is sent to the performance-chart clerk, where a graphic record of the worker's performance is made. The card is then sent to the time-study foreman, who, after approving, sends it to the general foreman. The general foreman makes his observations and returns the card to the Time-Study Department to be filed. By this method each of the interested parties are made familiar with the details of the trouble and are generally enabled thereafter to avoid a repetition of the same difficulty.

The performance-chart record furnishes valuable information to the foreman and superintendent when re-rating and selecting men for promotion. It also provides a ready means of checking the progress and development of new workers. The efficiency of an entire section or department may readily be determined and comparisons made between different departments throughout the works.

In comparing the standard-time system of wage payment with other well-known systems, one of the points that might be criticized is that the time spent in preparation for placing a standard-time allowance on a job is sometimes considerably more than required by other systems. This extra time, however, is necessary because all conditions must be normal, all superfluous motions eliminated, the mechanical features approved, and the design of the apparatus or part checked so as to be sure that the worker is working to the best advantage. The time allowance set under these conditions is quite likely to remain stable, the workman is able to figure his income with a considerable degree of accuracy, and the company is reasonably sure that the cost of the article is right. On the other hand, if a value is placed on the job without these precautions, many revisions will probably be necessary as the search for improvements goes on under the urge of increased earnings. It is even quite probable that a workman will hesitate to advance his ideas if he knows that improved methods will lead to reduced values. The unit of value, or "time allowance," is expressed in decimal hours, which is easily understood and is not subject to misinterpretation, while some other systems use special names for their units of

[1] Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

Presented at the National Meeting, Rochester, N. Y., of the Management Division of The American Society of Mechanical Engineers, October 26 and 27, 1927.

measurement, which, after all, are nothing but periods of time. The allowances for fatigue and personal needs are based on observations extending over many years and made on thousands of different jobs. They are easily understood by the workman, who has confidence in the justice of the allowances, based as they are on actual performances. It would seem that this procedure is to be preferred over the secret and mysterious allowances used in some other systems. In a plant such as the Westinghouse at East Pittsburgh where many of the workmen have had twenty years of experience with various and sundry wage-payment plans, they are almost as well informed as some of the experts, and any plan which cannot be readily explained and understood would fare badly. It will be noticed that in this plan of incentive wage payment there is no provision for compensating the foreman and other non-productive workers for any extra effort put forth. From the years of experience with various wage-payment plans it has seemed best to keep entirely separate any plans for compensating the productive and non-productive workers. That is to say, the productive worker should not provide directly through his own efforts the reward for extra effort given to the non-productive workers. It is granted that the interest in increased production should be a common one, but even the appearance of rewarding one group at the expense of the other should be avoided. Some systems provide that should the worker earn more than his regular hourly rate a portion of the extra earnings shall be given the non-productive workers for their efforts which have enabled the productive worker to produce and earn more than would otherwise be the case. The productive workman eventually becomes possessed of the idea that some of his earnings are being used to compensate the non-productive workmen.

Some other advantages of the Standard-Time System are that it is applicable to both standard and special lines of work. Again, the payroll work is simple, being only the hours allowed for the work multiplied by the standard-time rate. Further, the rate differential is so proportioned that while the incentive to speed exists, the lower rate is high enough to accomplish easily the change from incentive work to day work.

Although the results obtained from incentive systems have been remarkable, there are at the same time some disadvantages which occur from having a number of workers concentrating only on their own individual production. Each worker realizes that he is paid only for what he produces, and it is but natural that he should strive to increase his own output, regardless of everything else. He feels that he has no time to help out new men or give a fellow-worker a hand when he is in difficulties, and he is unwilling to lose time hunting lost material, or doing a little extra work for which he is not directly paid but which will improve quality, speed up work as a whole, or help out the supervisory force. Lack of cooperation between the men and the management and among the men themselves is often evident. In order to correct such conditions, the Westinghouse Company has devised a group system. That it has accomplished its purpose has been proved by successful application in many and varied lines within the company. It is not to be doubted, however, that its application in industry as a whole has been decidedly limited. It will be well, therefore, to set forth the fundamental principles upon which the group system is based, together with a discussion of its advantages and disadvantages, so that those who have not heretofore done so may see where the group system may be introduced to advantage in their own industry.

Assume that two workers of about the same degree of skill and working with the same effort work side by side on the same class of work. They notice that, although they work in about the same manner, they do not produce equal amounts of work each day. One will produce more than the other, depending upon the conditions met with. One may run out of material or may be delayed by tool breakage, or may experience any of the thousand-and-one delays which occur occasionally. The other man, in the meantime, is having a better run of luck, and he is able to produce more on that particular day. These two men, wishing to steady their daily earnings and to secure the fullest cooperation from each other, mutually agree to pool the work done by each, and at the end of each day make an equal division of the total. These operators, then, have formed a group. This same agreement may be made among three, four, or any reasonable number of men. When a group is formed by the men themselves, however, the number of members of the group is generally kept small; for the arrangement usually calls for an equal division of earnings, and only men who are capable of producing nearly equal amounts of work are willing to band together.

Groups formed by the men themselves occur in industry, but they are not common. Generally workers on the same class of work possess different abilities, and the greater producer is not willing to enter into an agreement with the lesser producer. Rather, groups are organized by the management, and a payment system devised whereby each man shares in the earnings of the group *in proportion to the amount of time* he works in the group and *in proportion to his ability*.

A group, then, is a number of workers working on the same class of product who pool the product of their labor, and the method of distributing the earnings of the group among the workers is known as the Group System of Wage Payment.

### Advantages of the Group System

*Better Cooperation.* There is greater cooperation among men in a group than among individuals. Since everything that will aid in the completion of the work will mean more money for the group and hence for each man, the individual is willing to help his fellow-workers whenever necessary. For instance, if a man needs help in lifting a heavy casting on to his work bench, he will get that help under the individual incentive system only when his neighbor has finished what he is doing and when it suits his convenience to give a hand. Help is often given grudgingly, and at times there is wrangling between the men, particularly if they do not happen to like each other for personal reasons. In a group, one man will set personal feelings aside and help another man willingly, because by so doing he knows that he is helping to increase his own earnings. This willingness to cooperate with one another increases with the length of time the group works together, until a group spirit is built up which will affect every man in the group.

Lost time caused by waiting for a moveman to bring more material, waiting for the tool room to grind tools, and other small delays which would cause the individual operator to lose time, is practically eliminated under the Group System. If the operator is forced to stop his own work for any reason, he will help another man in the group on another operation, or he will do some odd job which will aid the group as a whole.

Again, one man of a group will be more careful in performing an operation if he knows it will aid the next man in performing the following operation. For example, one man milling a casting which is then to be drilled will try harder to remove all burrs so that the piece will fit smoothly into the drill jig used by the next operator in the group. If any burrs must be filed off he will do this while his machine is making the next cut. Thus the drill-press operator can work steadily with no lost time. Such things, although small in themselves, amount to considerable time in the aggregate and will increase the overall group efficiency and consequent earnings to quite an appreciable extent.

There are always some jobs which are not as desirable from

the worker's viewpoint as others. The work may be heavier or more complicated than the average; it may be more disagreeable, or it may be a short order which will not allow the worker to get into the swing of the work and thus work more efficiently and make higher earnings. No matter what the cause, if the job is undesirable, under the individual system, there is a tendency for the operator to shun it in the hope that eventually some other worker will do it. This makes it more difficult for the planning department to get such jobs through the shop, and often these orders are seriously delayed. A group, on the other hand, realizes that it will eventually do the job and that there is no particular advantage in setting it aside and favoring other work. Thus the schedule clerk has merely to inform the group leader when the job is wanted to be reasonably sure of getting it. This materially lessens the work of the planning department, and tends to reduce the number of overdue orders.

*Reduction of Supervision.* Many workers object to so much being spent for overhead, for they feel that they are supporting the so-called non-productive employees. This feeling is minimized under the Group System, for the amount of supervision and hence the size of the non-productive supervisory force is greatly reduced. The group leader is, in effect, made an assistant foreman. He is, however, in much closer contact with the men under him than the assistant foreman would be for he generally has fewer men to handle, and he works side by side with his men. The group leader is personally interested in what his men produce, for their production affects his earnings, while, as a rule, assistant foremen are paid on a fixed salary basis independent of production.

The group leader gives instructions to his men and sees that they work properly. He makes certain that they are using the most efficient methods and that they interpret drawings and shop information properly. The foreman merely instructs the group leader in a general way, leaving to him the working out of the minor details.

The size of the planning department is reduced by the Group System. Instead of assigning jobs to each individual man, it tells the group leader what jobs are wanted next and leaves it to the group leader to get the jobs done. Obviously, it is easier for the planning department to deal with ten group leaders, each of whom supervises nine men, than it would be to deal with the hundred men as individuals.

Under the Group System, few instructors are needed. The group leader and the other men in the group all help to show the new man how to go about his work more efficiently. The new man tends to learn from members of the group in a shorter period than he would under an instructor since they are in more constant contact with him. The older men realize that the sooner they break in the new man, the sooner they will get the full advantage of his efforts. The new man is anxious to show the group that he is capable of working with them, so he strives more earnestly to learn than he would under an instructor.

*Reduces Non-Productive Labor.* Under the Group System it is often possible to include in the group material handlers and other service men so that they may share in the efforts and earnings of the group. For instance, suppose that one man is needed to bring materials to and remove finished work from a group of ten men. By increasing all time allowances applicable to the group by some percentage, it becomes possible to include the moveman in the group, and since his earnings are affected by the group he will be more willing to help them than when he was working as an individual and had no interest in greater production. The group leader will be quick to find simple jobs for him to do when he has no material-handling work to occupy him. In time this man will be able to learn to do the harder jobs, and eventually he may be able to take his place in the group as a full-fledged artisan, and, of course, will share in the earnings of the group to a greater extent. The service men as a whole will realize that they have a chance to improve themselves and get ahead, and it will be possible to get a better class of men to accept and keep such jobs. Labor turnover will be reduced, and at the same time new skilled workers are constantly being developed.

*Simplifies Costing and Time Keeping.* Where actual costs are determined on every job that goes through the shop, a very large cost staff is required under the individual system. Under that system each man that works on a job turns in an individual time slip on that job. When the job is completed, all the time slips are assembled. The amount paid each worker on each time slip is found by multiplying the time earned or the number of pieces made, as the case may be, by each individual rate. The total of those amounts gives the actual labor cost of the job. If the job comes through the shop later and is worked on by different men at different rates, the actual cost will be different. If a breakdown occurs while the job is being made and the worker neglects to turn in an extra time slip covering the delay, the job will be charged with the time lost, while in reality it does not deserve this charge.

Under the Group System the cost is computed from the average wage rate of the group multiplied by the total time allowance for the job. This makes a very simple method of costing. Unless the personnel of the group changes or unless there is an increase or reduction of wage rates in the group, the cost of making the job will be the same every time it goes through the shop. Minor breakdowns are not charged against any one job but are distributed over all jobs.

Time keeping is made much easier under the Group System. Each man turns in only one time slip a day. On it are his name, check number, group number, and the amount of time worked. The amount earned is figured either from the shipping report of the section or the shipping report of the group as made out by the inspector. Thus the time keeper has only as many time slips to handle each day as there are men in the group.

### Bonus Plans Adopted

As mentioned before, the problem of coordinating wage incentives and production control has been handled by the Westinghouse Company in a somewhat different manner than is usual in most systems, and some of the ideas that have served their purpose or now exist will be discussed.

During the World War when the need for production was so great that cost was a secondary consideration, the workmen were offered such incentives that unprecedented effort was given and the wages were enormous. At such a time it was useless to expect the foremen, clerks, and other non-productive workers to exert themselves proportionately for their regular salary which was perhaps one-fifth to one-half what a hard-working lathe hand could count upon earning. This was taken care of by the following bonus plans.

*Supervisory Bonus.* This plan provided for payment of bonus to the supervisory force identified primarily with production. It affected salaried employees observing shop hours and superintendents and assistant superintendents who did not observe shop hours. It did not include inspectors, time-study men, or time, cost, and estimating clerks.

Bonus was based on four factors:

1 Production
2 Percentage of Overdue Orders
3 Expense Control, and
4 Man Efficiency.

A load or "bogey" for each factor was set for each section on production as follows:

*Production*—Load fixed for each month by Central Production Department

*Percentage of Overdue Orders*—Bogey fixed for each month by the Central Production Department

*Expense Control*—Bogey based on past records and not changed from month to month

*Man Efficiency*—Bonus paid one-half the average percentage increase of the workmen's earnings over standard.

Five (5) per cent bonus was paid on each factor where load or bogey was met. Three (3) per cent bonus was paid where 95 per cent efficiency was reached. The bonus earned on all factors were added and the total represented the percentage added to the salary of each participant.

If efficiency fell below 95 per cent on any factor, no bonus was paid on that factor. If efficiency fell to 85 per cent on any one factor, bonus on all factors was canceled.

If the load was exceeded or if results were better than represented by the bogey, 1 per cent additional bonus was paid for each 5 per cent increase.

*Time, Payroll, and Checker's Bonus.* An allowance of $3.50 per month was made for handling the time and checking of each workman. An average was taken on the number of accounts closed in by the Payroll Department for the two pays of the month, and should this average, for example, be 1000 accounts, the total allowance for earnings of time and payroll clerks and checkers for that month would be $3500. Should the actual salaries of this group amount to only $2500, one-half the amount saved, or $500, would be paid the group as bonus, subject to the following deductions based on the equality of the service rendered:

1 Before prorating that portion of the bonus payable to the payroll and time clerks a deduction will be made of 50 cents for each pay shortage.

2 A 2 per cent bonus deduction will be made from time clerks and checkers for each 1 per cent error in the checkers' counts as revealed by the inventories. This deduction will be based on the average error of all operations.

On certain kinds of so-called non-productive work the output is not directly proportional to the effort expended, for example, material handling, receiving, storing, and issuing of raw materials and the like. Investigation on this kind of work has shown that with an increased effort of approximately 10 per cent on the part of the worker it is possible to increase his output about 100 per cent. As an example of this condition take the case in which a man goes to a storeroom presenting a requisition for one piece of a certain item. To supply this piece the storeroom attendant receives the requisition, refers to his records to locate the proper bin, goes to the bin, picks up a piece, and delivers it to the man at the window, recording the withdrawal in the ledger.

Had this requisition specified two pieces instead of one, the work involved on the part of the storeroom attendant would have been very slightly increased, yet the output would have been doubled. In order, therefore, to place work of this nature on an incentive basis, it is necessary that this condition be taken into account. The following formula was accordingly designed to be used in such cases:

$$(\text{Established Time} - \text{Time Taken}) \times F + \text{Time Taken} = \text{Time Allowed}$$

where $F$ is a factor representing the increase in effort necessary to bring about an increase of 100 per cent in the output. In most cases this factor is equal to approximately 0.10. An example will illustrate the method of figuring earnings from the formula. In a storeroom there is a group of nine men. In a certain pay period there were 96 working hours, or the "Time Taken" was equivalent to 96 × 9 or 864 man-hours. Material for 700 control-panel sections was delivered to the floor by the storeroom group at an allowed time of 1.50 man-hours per panel. The "Established Time" would therefore be equivalent to 700 × 1.50 or 1050 man-hours. Using a factor $F$ equal to 0.10 and substituting in the formula, we have,

$$(1050 - 864)\,0.10 + 864 = 18.6 + 864 = 882.6 \text{ man-hours allowed.}$$

This example shows the results obtained from a wage-payment system which is founded on the theory that the worker should be paid for the time taken plus some fraction of the time he saves; that fraction, which in the example was $^1/_{10}$, depends upon the amount of increase of effort required to give the increased output. In other words, if the worker does twice as much work to turn out twice as much product, he should be paid on a straight standard-time basis, or his incentive factor would be 1.0. If, however, as already explained, it is only necessary to increase his effort $^1/_{10}$ to double his output, this factor should be 0.10.

This method of figuring allowed time on work of a non-productive nature is used quite extensively at East Pittsburgh and appears to be looked upon favorably by the workmen, while it is quite interesting from the company's standpoint to know that excessive earnings, or earnings out of proportion to the effort expended, will not be possible.

Production, time, and cost clerks may increase their earnings by additional effort through a standard-time plan based on time necessary to get an order properly recorded, checked and into work. It might be well to state, however, that although this plan has been carefully considered and has all the earmarks of a practical plan, it is not yet in use.

The route through which an order travels in each section should be laid out in order to eliminate back-tracking and lost time.

Each stock order will be classified according to the number of different steps or operations through which it must pass. For example, an order calling for a certain type of apparatus, may require issuing a considerable number of requisitions, ordering parts from different feeder sections, drawing material from storerooms and requesting material through the Purchasing Department. Assuming that this order requires as much or more labor than any other, we shall call it Class A, for which will be established a time value in man-hours for performing the work. All orders requiring the same number of operations or within a reasonable amount to be listed in the same class. If the range becomes too great other classes may be established such as B, C, D, and E, for which separate time values will be set.

The time elapsing between the receipt and completion of the order will afford sufficient time in which to study and classify each order. The performance record will not be taken until the jobs are shipped.

All clerical help in a section that assists in recording, ordering material, issuing time cards, writing labor cards, shipping, or compiling costs in connection with an order, will constitute one group. The production clerk in charge in the section will be recognized as the group leader. It will be his duty to plan and supervise the work.

At the end of each semi-monthly pay period a record will be made of the number and classes of jobs shipped. The total number of jobs in each class will then be multiplied by the established time value which will give the total time allowed for each class. A total of the time allowed for the different classes will then be made which will equal total time allowed.

From the semi-monthly time reports will be taken the time actually worked by each member of the group, a total of which will equal the time taken. These time reports must be approved by the head of the division or some one to whom this duty has been delegated.

In order to calculate the earnings of the group, proceed as follows: $\frac{\text{Time Taken}}{\text{Time Allowed}}$ = Performance percentage. Opposite this figure in the table below will be shown the percentage to be added to the earnings of each individual in the group.

The flat wages of each member of the group will be increased by this figure except in such cases where an individual has been absent or late, when it will apply only to that portion of his earnings covering the time actually worked.

Overtime will be counted as time taken, but no compensation will be allowed in addition to that earned by the incentive plan.

When the percentage figures less than 10 per cent the group will be considered as having failed to qualify and will be paid their flat earnings.

| | Percentage to be added to earnings of each individual of group |
|---|---|
| Time taken more than time allowed | 0 |
| Time taken equal to time allowed | 10.1 |
| Time taken 90 per cent of time allowed | 11.1 |
| Time taken 80 per cent of time allowed | 12.5 |
| Time taken 75 per cent of time allowed | 13.3 |
| Time taken 60 per cent of time allowed | 16.7 |
| Time taken 50 per cent of time allowed | 20.0 |
| Time taken 40 per cent of time allowed | 25.0 |
| Time taken 30 per cent of time allowed | 33.3 |
| Time taken 20 per cent of time allowed | 50.0 |
| Time taken 10 per cent of time allowed | 100.0 |

It will be noticed that all persons up to the foreman in charge can be placed on an incentive plan. Some may feel that the foreman should be included, but experience has shown that it is well to have some person in charge of the group who will have no direct financial interest in the result and can therefore see to it that undesirable means are not used for obtaining temporary advantages.

It may be asked whether or not the incentives offered the workmen in the wage and bonus systems herein described, have any off-setting effect in increasing accidents along with increased production?

In view of the dismal accident record of industries generally, until comparatively recently, the question is a perfectly proper one.

It is beginning to be recognized that a really efficient shop is at the same time a safe one—that is, one phase of a business cannot be developed at the expense of another and in our own shops experience has borne this out.

Careful study has been made of every disabling accident over a period of several years and not a single instance has yet been found where an accident even remotely could be traced to excessive speed as a result of a wage incentive. Safety is never sacrificed to speed, but on the contrary there have been occasions where the reverse has been true, and the fact that our accidents have decreased 81 per cent in the past five years, is offered in confirmation of this statement.

Summing up in a few words, it would seem that coordination of wage incentives and production control can best be obtained by furnishing a common interest in greater output through entirely separate wage-incentive plans and compensation for the different groups involved.

## Discussion

G. D. Bearce.[2] The author clearly outlines the production control and bonus system used by the Westinghouse Electric & Manufacturing Company at East Pittsburgh. Further development of the standard-time system of wage payment is the most logical of any of the bonus systems that are in vogue. It assures the worker of a fair rate of pay and provides him with an incentive to increase his productivity.

The procedure termed the "fall down" method of keeping track of the ability of the worker should be very effective. The term, however, is quite harsh, and from the standpoint of psychology, the workman should not be accused of falling down, but rather have it brought to his attention that an "unfulfilled task" is charged against his record.

One of the first questions considered, when the bonus system is undertaken by a plant that has never had experience with wage incentives, is the cost of operation. The author might present information of this nature which would enhance the value of his paper.

In the discussion regarding the value of paying bonuses to non-productive labor, the fact should not be overlooked that doubtless considerable of this type of labor is necessary to operate any bonus system. Consequently if bonuses are not paid to non-productive labor, at least the added cost of operation for a bonus system should be deducted from any savings that such a system might make possible.

J. E. Dykstra.[3] While the writer personally believes that the standard-time system is as easily applicable to any plant as any of the various incentive systems, and more so than many, yet it would seem that the system outlined by the author would present problems in some lines of endeavor that would make its application, as a whole, a matter of some difficulty. Not every factory is so situated as to make a group system possible, and this is especially true of some of the so-called job shops, where quantities are always limited and size and quality of the work are greatly diversified.

The special benefits of the group plan are given under the heads of Better Cooperation, Reduction of Supervision, Reduction of Non-Productive Labor, and Simplifying of Costing and Time-Keeping. These four items enumerated are readily operative and applicable in all cases where production and the product itself permit the grouping of a number of individuals of similar skill, and where the production operations are somewhat similar. Assembling operations will most readily fall under this classification. We should, however, be mindful of the fact that there are many factories having departments employing from 10 to 30 people, and yet have in these departments such diversified equipment that everything from a crankshaft for a 300-hp. engine down to a special capscrew for a 10-hp. engine, or a clutch must be produced. Under such conditions, the writer believes that the four items just mentioned as a natural sequence of the group system become extremely difficult of realization, and that even the group plan itself becomes difficult of application.

The fourth item, Simplifying Costing and Time-Keeping, which could possibly be applied to the units produced as a whole, becomes at once an impossibility, when an accurate parts cost is necessary in order to determine a reasonable price for replacement parts. It naturally becomes impossible for one man to make out one time slip for a day's work when he may work on as many as a dozen or more jobs during the work day.

The second and third items, Reduction of Supervision and Reduction of Non-Productive Labor, also lose much of their possibilities under such conditions as those mentioned; and the first item, Better Cooperation, becomes largely a question of management and leadership.

Nevertheless, the outstanding items described by the author are perfectly applicable in all classes of manufacture. The most important items as the writer sees them are: The classification

[2] International Paper Co., New York, N. Y. Mem A.S.M.E.

[3] Factory Manager, The Champion Chemical Co. & The Foos Engine Co., Springfield, Ohio. Mem. A.S.M.E.

of equipment and manufactured parts; and a systematic time study, fully analyzing each operation and its tooling possibilities, plus a reminder system or "fall-down card," when any one employee fails to perform any operation within the time limit set.

It is surprising what faulty conditions can be brought to light when we once go through our various departments in the manner covered in the paper. No one would deny the benefits that can be obtained from an incentive system of wage payment, and usually some bonus scheme can be evolved to cover both productive and non-productive workers.

The writer has been able to obtain gratifying results under manufacturing conditions, similar to those described by the author by the creation of a contingent fund, consisting of a percentage of the premium earned by the productive workers during the month. This contingent fund provides for penalties in case of over runs on standards set, as well as work spoiled in the process of manufacture. It is at the end of the month divided on a predetermined basis, between department heads, non-productive and productive workers in the department.

It is fortunate for the engineering profession that no given system can be applied to all of our diversified manufacturing systems, but by judicious application and some modification, almost any of the recognized incentive systems can be profitably employed and can be introduced without any appreciable friction from the workers. It is needless to say that the simplest possible system that will bring results is the most easily introduced, and that no system should be introduced before a thorough study of its possibilities has been made under given factory conditions. The introduction of a system, when once determined upon, can best be accomplished by a competent member of the organization, perhaps under outside supervision of an expert, if necessary. Most schemes that are working satisfactorily are usually the products of a continuous growth and application, and quite frequently systems are working that bear only a fundamental resemblance to the scheme originally installed.

M. C. Rosenblatt.[4] Of the plan outlined by the author no criticism can be offered. This is to be expected, since the plan is backed up by many years of experience for these particular shops, and is the fruit of evolutionary processes where the good in previous plans has been retained and the bad discarded. The plan itself is accurate, commendable, and workable and should be increasingly successful if the principle behind it is fundamental. Whereas the details of the plan respond completely to logical analysis, it is a matter entirely of opinion as to whether the principle behind it is correct and will withstand the ever-changing labor conscience.

A wage incentive with the proper production control is made in order to increase the rate of production with the same facilities. It operates to create a greater profit for the invested interests. It does not, in itself, better the welfare of the operative any more than if the operative diverted his time when out of the shop to his own monetary profit, since he is giving more to production and quickly realizes this. If, by means of the wage incentive, overhead is decreased and, therefore, net profits increased and the wage incentive and a share of the extra earnings on the invested capital are linked together, then the best results will obtain.

Wage incentives in themselves have a tendency to produce inferior work, unless the operative or group is instilled with the thought that such work cuts down the net profit and indirectly reacts against him or the group and all of the workers where they are also interested in the net earnings of the business. If there is a tendency to produce inferior materials, greater supervision and inspection become immediately necessary, with the attendant negating of the monetary gain expected.

The rate at which work is turned out is a function of the operative's own natural ability and disposition, the facilities at his disposal and, primarily, his mental and physical health. The operative sets his own pace for any particular task to which he is put. The wage incentive merely adds an artificial stimulus and does not correct any of the fundamental factors of rate. This added stimulus must take its toll somewhere, which may be either in inferior work, greater mental and physical fatigue with the attendant greater turnover, or in other fashions.

The formality of bonus pay for the fast worker over a long period of time becomes commonplace and expected. He becomes accustomed to the higher rate and overlooks the fact that he earns more because he produces more. He finds in time a need for the higher pay and conveys this idea to his associates who may, in themselves, belong to the group of slow or awkward workers. The reaction does not set in until there is a change of employment when a higher rate seems to be demanded and a new plan evolved.

While the writer has no criticism to make of the plan so completely analysed by the author, he is not entirely satisfied that such plans, *per se*, are the complete solution. Capital produces the only unearned increment. The producer-consumer wage earner pays himself.

W. M. Passano.[5] The writer has had some experience with a system of wage incentive, similar to the one described by the author, but in the printing industry. In principle, our system of standard times and wage incentive is the same as that in operation at Westinghouse, and has been in successful use for the past six years. The fact that printing is virtually a craftsman's industry, and in this way differs somewhat from a strictly manufacturing industry, may account for the fact that certain modifications of the methods described by the author have proved desirable in our business.

The main point in which our experience has not agreed with the Westinghouse Company's experience is that we have found the group system not desirable, although in certain departments we have had to use it as a matter of necessity. It has shown itself unsatisfactory, from our standpoint, for the following reasons: First, the workers resent having a poor producer in the group. It has been said that when such is the case, the management should keep its hands off and the good producers will make it so hot for the poor producer that he will either have to get out or do better. Quite often, although it is impossible for him to do better, other good reasons exist for keeping him in the group. He may be a versatile man who can be moved from one department to another as conditions demand, or he may be a very old and loyal employee. From the management's standpoint, these reasons will be sufficient to continue employing the poor producer, although the workers cannot see it this way.

Second, we have found that the workers in a group go even to the point of resenting the management's hiring inexperienced help. They point out that hiring experienced help, by paying higher wages, would make it unnecessary for them to spend time in teaching the inexperienced.

Third, the chief disadvantage we have found with the group system is that by not keeping a record of the individual's production, we lose a desirable control of the situation. We use the individual's production record as a basis for increases in pay and laying off in dull seasons. This would have to be left to the foreman's judgment if the record of the group were all that were known.

[4] Specialist in Acoustics, Philadelphia, Pa. Assoc-Mem. A.S.M.E.

[5] Waverly Press, Inc., Baltimore, Md. Jun. A.S.M.E.

On the other hand we have felt keenly all the disadvantages of the individual incentive system which the author describes; but it has been our aim to attempt to devise ways of eliminating these weak points. The undesirable features of the individual incentive methods and the ways in which we have attempted to correct them may be listed as follows:

1 When a productive worker is delayed for any reason, such as helping a fellow-worker, teaching a fellow-worker, lack of material, or anything beyond his control, he is permitted to note on the back of his time ticket the number of minutes that he has been delayed. Then this amount is deducted from the time taken to perform the operation.

2 We too have experienced the condition of slighted work due to the men's anxiety to make high records. Our system is to return all unsatisfactory work to the man who originally did it, and let him make it good without receiving any credit for the time so spent. Where this is not practical, a record is kept of the cost of correcting the poorly done work, and this cost is deducted from his bonus.

3 Of course, it is impossible to have all jobs equally difficult or equally desirable, and if the men are left to their own resources, they will, naturally, fight shy of the short-takes and mean jobs. We have established the system of having the foreman distribute the work among the men in an impartial way, so that each man gets a part of the fat and lean.

4 The author mentioned the advantage of a working foreman with a small group. We have found it equally advantageous to have a working foreman in charge of a group of men who are *individually* rewarded for their production.

5 We have established a method of obtaining standard unit costs with a minimum of clerical work, despite the fact that each man receives an incentive in proportion to this *individual* productivity. As our scheme may be interesting a brief description of it follows.

Each man works on only one time ticket per day. On this ticket he lists the operations on which he works and the number of units that he produces. By detailed time study, we have determined a standard time for performing each of these operations, and the clerk at the end of the day computes the standard time allowed for the work which he has done. The actual time, of course, is taken from the time ticket. The standard time divided by the actual time is the man's efficiency. Similar records are kept for every one in the department, the average of which gives the efficiency of the department.

To determine the unit cost of any operation, it is necessary simply to take the standard time for the operation, divide it by the efficiency of the department and multiply the quotient by the *hour rate* of the department.

It is interesting to note that we do not attempt to keep separate time records on individual jobs or operations, but that we obtain standard unit costs, which are bound to be correct on the average.

Although many have felt that it is impracticable to attempt to standardize a craftsman's industry, we have found that rewarding the workers, in proportion to their production, has proved most profitable in the printing business.

J. F. Mattern.[6] Many shops of much smaller size than the one described by the author are endeavoring to discover some means of setting time allowances whereby a man is assured of a little better rate of earning, provided he uses extra effort and gets out more work in a given time. There are just as many different means of arriving at this end as there are shops working on the problem. There are, no doubt, many shops in which time-allowance systems have been tried and subsequently have been thrown out. If we were able to get definite data on the various reasons for failure of time allowance systems, we should very likely come back to the fundamental basis of all of these systems, and that is the method of setting the rate in an equitable manner and the stabilization of the rates in just as equitable a manner.

The author states that standard time allowance is established on each operation or job. He describes the motions for checking the efficiency of each worker by means of the "fall-down card." He subsequently handles the fall-down card clear through the organization until it gets back to the time-study file. The amount of work involved in handling this card would make a big impression on the small shop executives, in view of the number of persons involved. The amount of clerical work involved, the time of supervisory checking and comments, the final recording on the performance card all take time and money. This brings us to a question.

Are any data available which will show the approximate cost in time and money, to set a standard time allowance for an operation, handle the time cards, make out a fall-down card, interview and check the worker for his side of the story, get the foreman's comments, check up all the performance charts, check on the time-study foreman, refer to the general foreman, and then to the time-study department for comment and file?

Another question along the same line, which ties up with the first question, is: What percentage, in the light of experience, of the total number of standard time allowances handled, would be estimated for "fall down?"

These two questions are fundamental, and they are of vital importance to a shop executive who is looking for a means to increase his output per man and still trying to keep this man well paid and consequently happy. Not many organizations are as large as Westinghouse, and very few industries could support the overhead charges of such a system, particularly if the shop is engaged in irregular work of a jobbing nature. If the author can give us a general answer on these two questions, many of the executives in smaller shops will get an entirely different view of the possibilities or impossibilities of using similar systems in their own shops.

J. G. Wegman.[7] The plan proposed by the author is entirely consistent in most respects. On one point, however, the writer has a divergent point of view.

It is apparent that the author does not approve of permitting foremen to have any direct financial interest in the effort earnings of the productive operators. However, he grants that the interest in increased production should be a common one. So many influences affect productive effort and earnings that to divorce the productive operators' and foremen's incentives or rewards for extra efforts would at once separate many other interests that must be common.

Inherent higher productive operators' earnings, where there is mutual or common incentive, leaves absolutely no doubt or question in the productive operators' minds as to mutual integrity toward the common goal of each. Reciprocity becomes a factor in every phase of departmental operating.

The incentive plan, when mutual, wherein it is possible for the productive operators' efforts and earnings to peak and the foreman's earnings to show no increase is rapidly bringing out increased attention to each and every phase affecting the productive operator.

To bear out this statement consider the foreman, assistants, and group leaders who find it to their direct monetary benefit to manage in their own spheres with the following factors to consider and improve: operators' earnings, costs, source of supply, quantity and quality of supply, job rates and operators'

[6] General Superintendent, Elliott Company, Jeannette, Pa. Mem. A.S.M.E.

[7] North East Electric Co., Rochester, N. Y.

rates, day work, waste, overtime, idle time, production schedules, time studies, methods and method changes, clerical work, trucking, and janitor labor; each of these directly affecting the foreman's earnings. Is it not plain that productive operators will get more intelligent service under a system of this nature? And is not this service insured when a foreman's earnings are proportionate to the degree in which the service is rendered?

In making the incentive common to productive operators and foremen we simply bond together all interests that should be common. And here mutual cooperation becomes conspicuous because of the reward affecting every person.

When productive efforts prove above normal and the individual productive or non-productive operator is paid in direct proportion on the same basis, the productive operator is quick to grasp and appreciate that he and the so-called non-productive operator or foreman and his assistants are incentively bound to a common goal. He sees non-productive labor at his service more than ever, all because of this service reward. And, further, his constructive demands become more numerous. For example, as foremen, we may often allow some weakness in conveyors or other devices to be temporarily neglected. Now, if foremen and men are bound together by a common incentive plan, the men will not hesitate to call such matters to the foreman's attention. They not only know that they have an absolute right to do so, but they know that it is to the mutual interest of the foreman and themselves that they do so.

Under other plans need the foreman be so aggressively interested in the operator when the reward of each is not common and interdependent? He should be, but is he?

Base service rewards on anything you will—they inherently show where all interests must be vitally common and each dependent on the other, and impelled by an incentive that is a common one towards the common goal of livelihood. Therefore, how can it be possible to place in separate incentive spheres the productive operator and his foreman?

Surely we would not be influenced sufficiently to divorce interests that should be common, by the remote possibility of the use of undesirable means to gain temporary advantages by a foreman or his productive operators. Unfortunate incidents of this nature are, as a rule, traceable to morale that has been warped by neglect of common sense or economic unbalancing from any cause. Has industry grown to its present size by the use of undesirable means to gain temporary advantages? Or has it grown by just the same impulse that started it—confidence in someone else?

With our nation's largest and most successful industries striving constantly to have their employees assume direct financial interest by any number of attractive plans to the extent of $450,000,000 in employee-stock ownership, the writer cannot believe that anything is jeopardized where foremen and operators are bound in common interest by a common incentive.

Ray Flagg.[8] In the first part of the paper the author states that if a worker performs a task in the allowed time or less, he is paid for the time allowed at his standard-time rate, which is a certain percentage higher than his "hourly day" rate. This would indicate that when a worker does a job in less than the allowed time he gains in two ways. He is not only paid for more time than he really puts in on the job but he is also paid for this time at an advanced rate. This would mean that mistakes in setting standard times would be doubly disastrous, and since some mistakes are sure to occur it would be interesting to know how much trouble this causes.

In order for a wage-incentive system to function to its best advantage, the worker must be given a guarantee that the standard time will not be cut for some definite period after it has been put in operation in the shop. If this policy is pursued in the case of the author's system, the setting of the so-called "allowed times" would have to be done with a degree of care that would make them exceedingly costly as well as slow to work out. From the description given of the methods used to determine "allowed-times," it appears that the executives of the Westinghouse Company appreciate this weakness in this system and have employed such measures as are at hand to minimize its effect. In this connection, the author should tell us on what this percentage increase of the "standard-time rate" over the worker's "hourly day rate" is based, and about what this percentage amounts to in dollars and cents. He also should tell us if the Westinghouse Company guarantees that it will not cut a standard time for any given period after it has been put in use?

Under the heading of reduced supervision the author points out that by applying this incentive system to a group of workers rather than to individuals, the amount of supervision necessary is lessened. The writer doubts this, for it has been his experience in handling groups that it is very difficult to get satisfactory group leaders. If it were possible to get group leaders who are willing to spend the extra time and effort that is required to manage a group, without any additional compensation other than a share in the additional earnings of the entire group, the author might be right. Again, a group of men is not curbed by conscience as is an individual. A group of men will do things to other groups and to their employer that the individuals composing the group would never think of doing as individuals. In the light of these facts it would seem that really what happens in this case is not a lessening of the amount of supervision necessary, but rather a shifting of it to other shoulders. Could the author tell us just what trouble, if any, the company has had in procuring satisfactory group leaders?

Under the heading "Simplifies Costing and Time Keeping," the author states that under the group system the cost is computed from the average wage rate of the group multiplied by the total time allowed for the job. This probably would average correctly over long periods of time, but on comparatively short jobs or jobs on which a part of the men in the group worked, it would unquestionably lead to very serious error. Also in the case of "fall downs" and the like, this average could not hold. Is this system used generally on all jobs where this wage incentive is used, or only on jobs where the entire group works on the job and the task is completed in the allowed time?

There is no doubt but that this system does aid in the costing and time keeping as long as the entire group is employed on a single job, but is likely to lead to complications under any other set of conditions. With these facts in mind, it would seem that this system is only usable in old established concerns where the output is thoroughly standardized and large enough in volume to employ groups of workers in place of individuals. This system likely works well in the Westinghouse organization, and for its needs it probably would be hard to improve it. The scheme used to induce the workers on the non-productive payroll to render better service accomplishes its purpose very creditably, but it too could not be expected to function under different conditions.

To judge a system of this character, without a knowledge of the executives back of it, and of the factory conditions under which it works, is apt to be misleading. An inferior system well managed will often give satisfactory results while an excellent system poorly handled may fail miserably.

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MAN-50-4

# Production Control in a Wrought-Brass Mill

By W. R. Clark[1] and Arthur Brewer,[2] Bridgeport, Conn.

*This paper describes the scheduling system which has been worked out satisfactorily during the past two or three years in a brass mill. The object of this system is to give better service to customers, to reduce inventories, and to stabilize employment. The paper contains flow sheets of the operations involved and is illustrated by charts and tables showing the variations of flow of material and the mechanism of control. The detailed procedures are outlined. The system accomplishes the following results: it enables careful prediction of the rate of production and means for planning it to meet current business; it enables prompt notification to the customers of the expected date of shipment and insures the fulfilment of this promise; in keeping productive facilities elastic, it permits the control of semi-finished and finished stocks, the control and reduction of inventories, and an accurate determination of mill hours and number of employees, the whole stabilizing the production rate and ironing out the fluctuation in cost due to variation in the volume of orders.*

This discussion will be confined to that section of the Bridgeport Brass Company known as the Mill Products Division, which has to do with the manufacture of brass and copper sheet, rod, wire, and tube.

These products are sold to the trade or delivered to the Fabricating Division of the company. The latter is the largest single customer of the Mill Products Division and for purposes of this paper will be considered as any other large customer. The sequence of manufacture is generally as follows:

## Flow of Materials

Copper, zinc, and brass scrap are the principal raw materials used. (See Fig. 1.[3]) With the exception of certain copper shapes purchased outside, these materials are weighed out in the mixture department to produce the various mixtures and are then placed in metal boxes, each containing approximately 220 lb. These boxes are check weighed and delivered to the casting shop by conveyor where they are placed on the charging floor by overhead traveling crane. In the casting shop the materials are melted in induction electric furnaces and the contents poured into molds of various shapes. These molds produce tube shells, round billets, and flat bars in various sizes and lengths up to 6 ft. long. Tubes are produced either by cold drawing direct from tube shells or by first hot piercing round billets and then cold drawing. The number of cold draws necessary runs from a minimum of two to a maximum of twelve. Annealing, pickling, pointing, and sawing operations are required between draws. Rod and wire are produced by first hot extruding round billets, hot rolling round billets or cold rolling flat bars, and then cold drawing to the finish size. From one to seven cold draws are necessary with annealing, pickling, and pointing between draws. Sheet is produced by cold rolling flat bars or first hot rolling flat bars and then cold rolling to finish gage. From three to nine cold rollings are necessary with annealing and pickling between rollings.

The finished products are made in a large variety of mixtures, sizes, and degrees of hardness or softness. Because of this great variety it is impossible to stock a great amount of finished material, except in the standard rod sizes used in screw machines and the standard brass-pipe sizes used in the building trades. Semi-finished stocks are maintained at various points, however, to facilitate quick delivery of finished product.

The major problem consists of maintaining a rapid and even flow through the mills of the materials required. It requires the maintenance of an active semi-finished stock at certain points

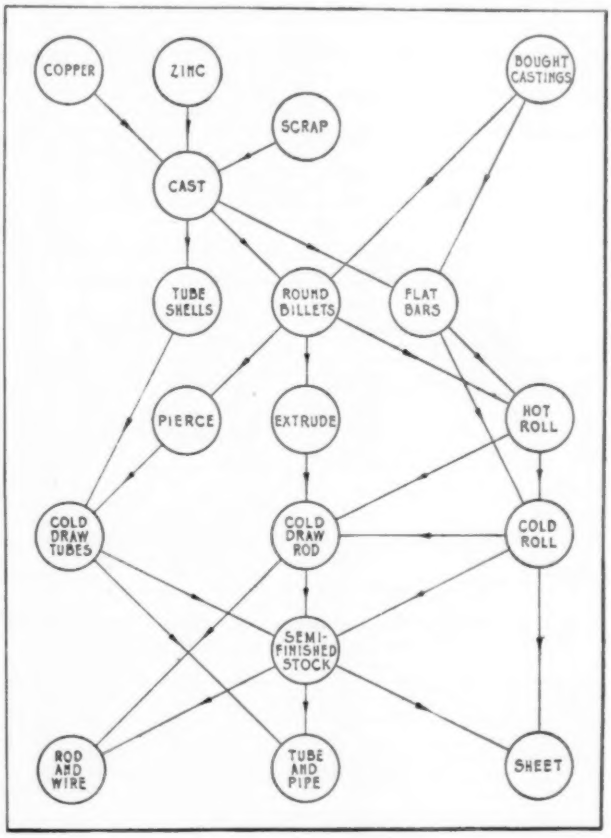



Fig. 1 Flow Chart

in the manufacture from which various sizes and tempers can be finished. It necessitates the grouping of small orders calling for similar sizes and materials into larger lots for more efficient manufacture. Production and shipment of each order must be accomplished at the time specified.

Normal capacities for a normal working week of 50 hours have been worked out for the various groups of equipment. Variations in the working week and the number of employees are predetermined, based upon the condition of the order balance and the sales department's estimates of forthcoming business.

## Order Balance

When an order is received by the sales department it is given a place in the production schedule and the customer is notified when the order will be shipped. As this acknowledgment must be made promptly, it should be made by the sales department. The shipping date must be accurately set, so that the mill can

[1] General Works Manager, Bridgeport Brass Company. Mem. A.S.M.E.

[2] Works Manager, Mill Products Division, Bridgeport Brass Company. Mem. A.S.M.E.

[3] Figures on all charts are fictitious and are used only to show relationships. Ratio of fluctuations represent actual conditions.

Contributed by the Management Division and presented at the Annual Meeting, New York, December 5 to 8, 1927, of The American Society of Mechanical Engineers.

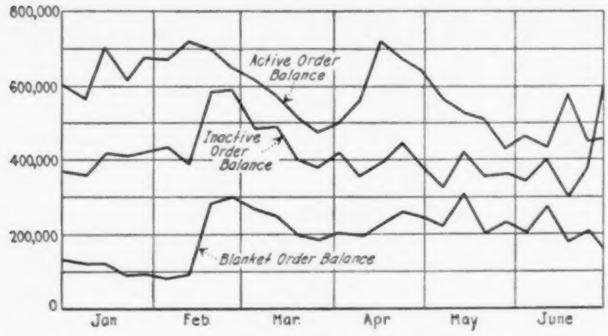



Fig. 2 Order Balances—Sheet Mill

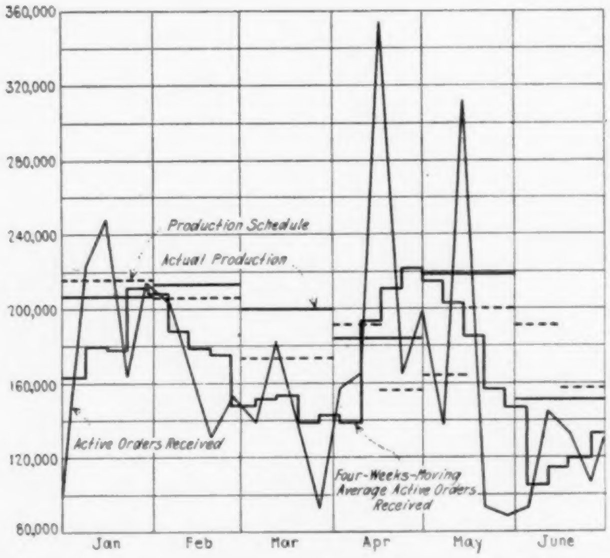



Fig. 3 Weekly Orders Received, Production Schedule, and Production Sheet Mill

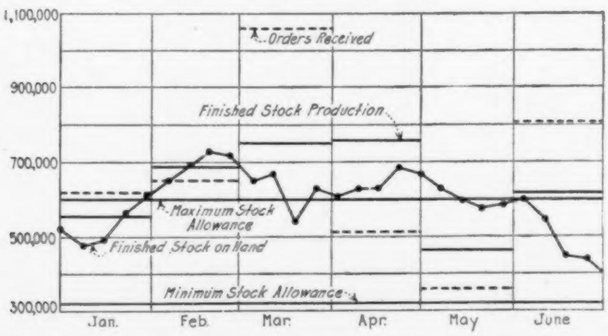



Fig. 4 Finished Stock, Iron Pipe Sizes, Plumrite Brass Pipe

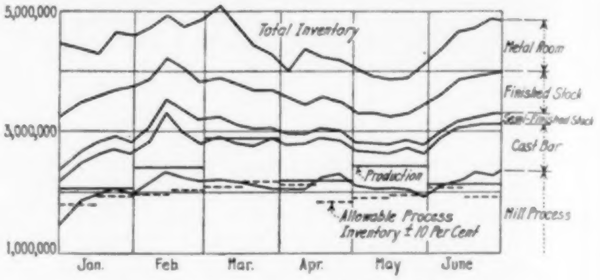



Fig. 5 Inventories—Curves Plotted Cumulative

| | |
|---|---|
| ESTIMATED INITIAL ORDER BALANCE | 500,000 lbs. |
| ANTICIPATED NEW ORDERS | 1,000,000 |
| SUM | 1,500,000 |
| ESTIMATED FINAL ORDER BALANCE | 600,000 |
| SHIPMENTS SCHEDULED | 300,000 |
| DESIRED CHANGE IN FINISHED STOCK | − 100,000 |
| PRODUCTION SCHEDULE | 800,000 |
| DESIRED CHANGE IN SEMI-FINISHED STOCK | + 200,000 |
| DESIRED CHANGE IN PROCESS INVENTORY | + 100,000 |
| METAL REQUIREMENT - NET | 1,100,000 |
| ESTIMATED MILL SCRAP | 200,000 |
| MILL REQUIREMENT - GROSS | 1,300,000 |
| PRODUCTION PER NORMAL MILL HOUR | 4,000 |

| | ANTICIPATED NEW ORDERS | CHANGE IN FINISHED STOCKS | PRODUCTION SCHEDULE | CHANGE IN SEMI-FINISHED STOCKS | CHANGE IN PROCESS INVENTORIES | GROSS MILL REQUIREMENT | NET METAL REQUIREMENT |
|---|---|---|---|---|---|---|---|
| SHEET | 700,000 | -100,000 | 700,000 | +50,000 | -150,000 | 700,000 | 600,000 |
| ROD & WIRE | 800,000 | +100,000 | 900,000 | -50,000 | + 50,000 | 1,200,000 | 500,000 |
| TUBE & PIPE | 1,000,000 | -100,000 | 800,000 | +200,000 | +100,000 | 1,300,000 | 1,100,000 |
| TOTAL | 2,500,000 | -100,000 | 2,400,000 | +200,000 | 0 | 3,200,000 | 2,600,000 |
| CHANGE IN METAL ROOM INVENTORY | | | | | | | +100,000 |
| TOTAL NET METAL REQUIREMENT | | | | | | | 2,700,000 |
| NET CASTINGS TO PURCHASE OUTSIDE | | | | | | 400,000 | |
| NET CASTING SHOP PRODUCTION | | | | | | 2,600,000 | |
| GROSS WEIGH-OUT FOR CASTING | | | | | | 3,000,000 | |

Fig. 6 Production Schedule—Tube Mill

| | MONTHLY SALES BUDGET | ANTICIPATED NEW ORDERS FOR THE MONTH | ACTUAL MONTHLY RATE OF ORDERS RECD. | ORDERS RECEIVED TO DATE | ACCUMULATED PRODUCTION TO DATE | MONTHLY PRODUCTION RATE | MONTHLY PRODUCTION SCHEDULE |
|---|---|---|---|---|---|---|---|
| SHEET | 650,000 | 700,000 | 750,000 | 270,000 | 280,000 | 600,000 | 700,000 |
| ROD & WIRE | 850,000 | 800,000 | 700,000 | 250,000 | 305,000 | 850,000 | 800,000 |
| TUBE & PIPE | 600,000 | 1,000,000 | 800,000 | 330,000 | 306,000 | 850,000 | 800,000 |
| TOTAL | 2,400,000 | 2,500,000 | 2,350,000 | 850,000 | 900,000 | 2,500,000 | 2,400,000 |

Fig. 7 Weekly Order and Production Report

accurately fulfil the promise made. To insure this the sales department must be governed by definite limitations.

About the middle of each month representatives of the mill and the sales department meet to set a production schedule for the following month. Just prior to the first of the month they again meet to discuss modifications in the schedule, if necessary.

In order that the rate of production shall be properly set, curves are kept showing the order balances (see Fig. 2). These order balances consist of (*a*) blanket orders, namely, orders—size and date of delivery to be specified later—covering a customer's 30- or 60-day requirements, so that he may take advantage of the metal market, or coverage on his contracts; (*b*) inactive orders, namely, those specified for delivery within a period greater than 30 days; and (*c*) active orders, namely, those required within 30 days. These curves show the metal obligations and regulate the purchase of raw materials.

### Orders Received

Curves are kept showing the current receipt of orders and their relation to the production schedule (see Fig. 3). As the rate of receipt of orders varies greatly, week by week, a four-week moving average also is plotted in order to smooth out these violent fluctuations. These curves, with information received from the salesmen in the field, after due rationalization,

form the basis of estimates of the probable incoming business in the immediate future. They also give a very clear picture of past experience.

### Finished Stock

Curves are kept showing the condition of finished stocks and their relation to shipments and production. (See Fig. 4.) Where possible, the production of stock is used to compensate for the variation in production of active orders, thereby stabilizing mill operation.

### Inventories

Curves are kept showing the condition of the inventories. (See Fig. 5.) These curves are cumulative: (*a*) mill process inventory plus (*b*) castings on hand plus (*c*) semi-finished stocks plus (*d*) finished stocks plus (*e*) raw material. Maximum and minimum allowable inventories are set monthly by formula, depending on the production schedule. These curves with the production schedules form a basis for the setting of the requirements for raw materials.

### Production Schedule

The product of each mill is divided into groups, such as condenser tubes, heater tubes, pipe, and miscellaneous—the latter being divided into five sub-groups, depending on size and gage. A production schedule is then made up for each group based on the order balance, anticipated new orders, and desired change in finished stocks. The combination of the groups gives the total mill schedule. (See Fig. 6.) The production schedule combined with changes in semi-finished stocks and process inventory gives the net metal requirement. This metal requirement combined with the expected scrap to be made in process gives the gross mill requirement. The normal mill hours for the month divided into the production schedule gives the production schedule per normal mill hour, indicating the labor-hour requirement for the month.

A summary of all the mills gives the total anticipated new orders, changes in finished stocks, production schedule, etc. The net metal requirement combined with the desired change in the metal-room inventory gives the total net metal requirement. The gross mill requirement is divided into outside purchases and castings to be made in the casting shop. The weigh-out then is indicated to produce these castings. The total net metal requirement is broken down to show the amount of each raw material required to produce the adopted schedule.

From this detail of the net raw-material requirement the purchasing agent can accurately purchase or specify delivery on contracts in accordance with the exact amount of each raw material required. Thus, by insuring that we have only the necessary raw materials on hand and controlling the process and stock inventories, the total inventory may be kept to a minimum, thereby producing the maximum metal turnover.

### Order and Production Report

Should the rate of incoming orders change suddenly, these production schedules can be immediately revised. A weekly order and production report is made, showing the relation between the monthly sales budget, anticipated new orders, and actual rate of receipt of orders. (See Fig. 7.) These figures give an immediate indication of a desirable change in schedule. The orders received to date and the production to date are accumulative for the month. A comparison of the monthly production rate and the monthly production schedule gives an indication of how well the mill is living up to the schedule adopted.

### The Monthly Schedule

The monthly schedule is divided into periods of a week's duration. A Kardex Rand Chaindex pocket is made out for each group and period. As each order is received it is transcribed on to a production-order form and a Chaindex Card is made out in triplicate and placed in the correct pocket for the period in which shipment is to be made. (See Fig. 8.) Identical Chaindex files are kept in the sales department, the production office, and the mill superintendents' offices.

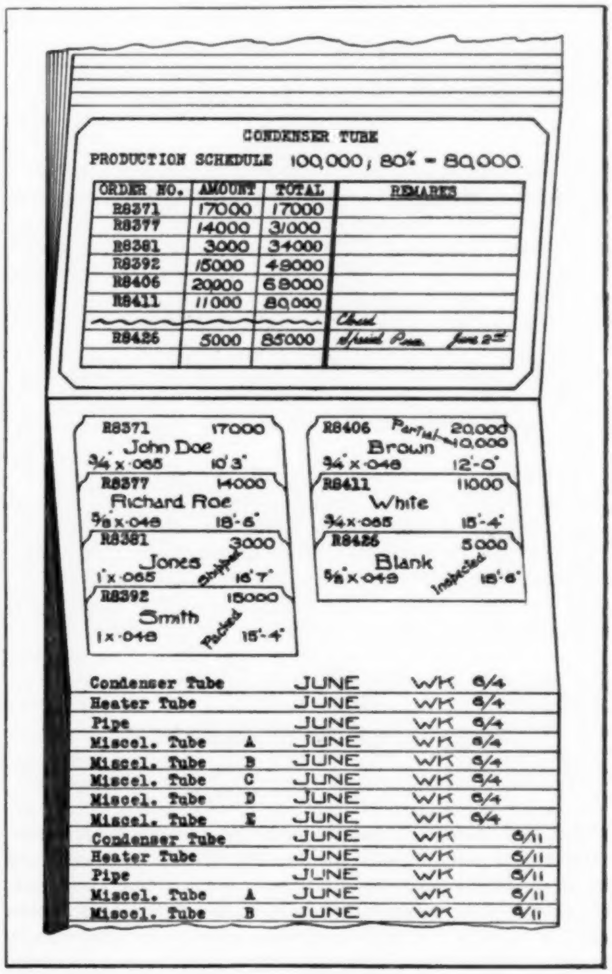



Fig. 8 Chaindex Schedule Records

Some groups require more time than others to produce after the receipt of order. Therefore, schedules are closed one, two, three, or four weeks, as the case may be, before the shipping date. Schedules are also closed when the total amount allocated to any group and period reaches 80 per cent of the production schedule. This 20 per cent reserved capacity is kept open for such hurry orders as may afterward be received and to allow flexibility in mill operations.

A card placed on the back of the preceding pocket carries the accumulated total scheduled to date. This gives at all times the open capacity or the over schedule as the case may be.

After a schedule is closed the sales department may add only such orders as the mill production office can accept with a certainty of delivery. Special promises to better previous scheduled dates are made only after the mill production office has made a special investigation to insure fulfilment of the promise given, without jeopardizing delivery of orders already scheduled.

As the various orders are produced the Chaindex cards are

stamped "inspected" or "packed" if shipment cannot be made immediately and "partial" or "shipped" if sent. At the end of the period all cards for filled orders are removed and discarded and cards for orders not shipped complete are placed in a pocket marked "carry over." Carry-over orders not produced become the most important items for the following period.

This Chaindex record gives at all times a complete picture of when each old order is scheduled, how completely each schedule

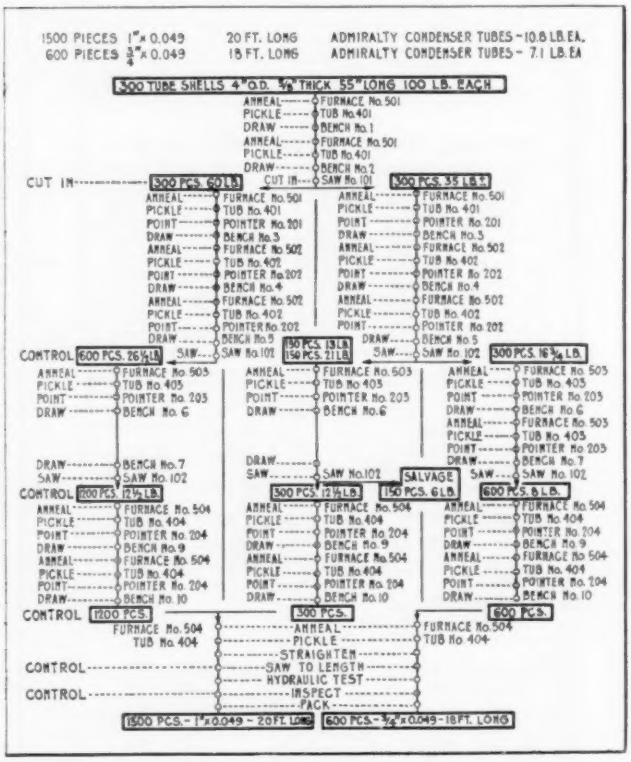



Fig. 9 Operation Chart

is filled, and where each new order can be placed in the schedule.

The record of the finished stock on hand is kept on stock cards placed in similar pockets. The drawers containing the schedules and stock records are kept in a cabinet on the desk of each schedule clerk in the mill production office. By their use he can answer promptly almost any question that may be asked.

## Operation Chart

Material is processed through the mill and shipped on the production-order form made out upon receipt of the order. A schedule clerk in the mill production office arranges for the castings to be made. He has the castings delivered with the production order to the mill superintendent, who is responsible for making shipment as scheduled.

The following of the orders through the rod and wire mill and the sheet mill is a comparatively simple matter. In these mills the material started on one production order is rarely transferred to any other production order. Thus, the different orders follow each other through the various operations to the finish. Only one dimension is changed in each cycle, i.e., diameter or thickness producing greater length. Due to the ease of coiling rod, wire, and sheet, the original casting is rarely cut into a number of pieces until finished.

Conditions in the tube mill, however, are quite different. (See Fig. 9.) Two dimensions are changed in each cycle, i.e., diameter and thickness and the ratio of these two changes must be kept within rather narrow limits. As the tube cannot be coiled, it must be cut into a number of shorter pieces as it elongates. This cutting usually occurs every second cycle. Tubing is usually ordered in a definite diameter, thickness, and length and therefore a definite weight per piece. The original casting rarely cuts to the desired weight without having a piece left over. Therefore, the material in each original casting must usually be applied on two or more orders to avoid undue scrap. Short pieces are held in salvage stock, which may later be drawn down to fill small orders when the opportunity arises. Great care must always be exercised not to allow this salvage stock to become excessive. Only careful and efficient planning can keep the scrap and salvage at a minimum and at the same time make shipment on all orders as scheduled and keep all machines and men supplied with work at all times.

This planning must of necessity be done by the superintendent of the tube mill and his assistants. As the production orders are received by him they are classified as to mixture and size of casting required. The schedule dates of the orders in each group must be watched and in due time material must be started. Material is usually started in 30,000-lb. lots, or six crane loads, each crane load carrying a work ticket bearing its lot and load number.

When a lot reaches the cut-in saw the sawyer is given a cut-in ticket telling him how many pieces to cut on each order and the weight of each piece Work tickets are given him to carry each crane load through to the finish. These work tickets give each subsequent operation, so that each operator in turn knows what he is to do when he gets the load. Each subsequent cutting is a control station and the sawyer must insure that every load in the lot originally cut-in is accounted for. He is given the original cut-in ticket to know what to expect. In case of undue loss through breakage or other cause he must see that more material is cut-in so that it may be rushed through and delay on the complete shipment avoided.

The crux of the whole procedure is the proper laying out of the cut-in so that undue scrap or salvage does not result, and the control stations at the subsequent cuttings to insure that no load or material is lost or delayed in its progress through the mill. Due care must also be exercised to see that each order is started in time to reach the packing room by the scheduled date of shipment.

## Conclusions

A careful prediction of the rate of production necessary to meet current business has accomplished the following:

1 Prompt notifications to the customer of the expected date of shipment and the fulfilment of this promise, thereby giving the customer accurate information.

2 Keeping the productive facilities elastic, thereby making delivery as near as practicable to the date desired by the customer.

3 Control of semi-finished and finished stocks, thereby making quick delivery possible when necessary.

4 Insurance that the productive capacity is not oversold, thereby avoiding dissatisfaction through delayed deliveries.

5 Keeping the sales manager informed on open productive capacities, thereby tending to keep production to a maximum in all lines.

6 Control of inventories and the acquisition of only the necessary raw materials, thereby reducing inventory and increasing metal turnover.

7 Accurately predetermining the mill hours and number of employees, thereby stabilizing labor requirements and reducing labor turnover.

8 Stabilizing production rate, thereby reducing the manufacturing cost.

## Discussion

S. P. Johnston.[4] Our problem in manufacturing aluminum bar and rod products is evidently very similar to the author's problem in connection with brass. We have, located at Massena, N. Y., a new unit whose sole function is the production of commercial rod of the type used in the screw-machine trade, etc. This unit is relatively new, having been put into operation within the past few months. Up until that time we operated on a rather small scale, as the demand was relatively light. There was no great attempt or real necessity at the time for a complicated system of production control on such a small scale, where a few people in direct charge were able to handle the mill.

The production has increased, however, so that we now are interested in putting into operation a system of production control very similar to that described by the author. Our plants are rather widely separated from our main office. At the Massena works we have a representative of the sales department, whose function is to maintain a control between the demand and mill supply. Orders are sent to the mill as received through the various sales offices, and the schedules are made up at the mill. We schedule on a weekly basis, and an attempt is now being made to evaluate our capacity in various classes of production, so that we may plan to put on schedules approximately 80 per cent of our active capacity and reserve the balance for rush orders.

At the present time the schedule of our capacity is somewhat in excess of the demand, so that orders are placed on the mill schedule almost immediately. We maintain in the mill itself a planning section which receives schedules from the main planning division and is responsible for getting them out. We use a "Lot Ticket" scheme, whereby as the orders are received in the mill, the various operations are listed by the planning department, written up on a "Lot Ticket," and dispatched to the various operations.

We maintain control stations where weights and various dimensions are checked. We do not maintain any stock of finished rod at the mill other than a small amount of standard sizes which accumulate due to the overages in production. At the present time, however, we are building up a warehousing scheme which we hope will go a long way toward stabilizing production in the mills. Warehouses are being set up at various points throughout the country, and the demand at present indicates that certain standard sizes can best be carried in warehouse stock.

At the present time we deliver from the mill, on average-size lots, in from three to four weeks. We have had difficulty in the past in meeting delivery promises, but at the present time we meet approximately 90 per cent of our promises.

William Kushnick.[5] The writer's company employs only about 300 people. The control system in use has worked during the last six months to a 95 per cent fulfilment of promises made. Promises are made by the week in about 50 per cent of the orders, and to the day in the balance. If a customer specifics to the day, an effort is made to deliver on the day desired. Our usual estimates of delivery are from two to three weeks for a manufactured order. About 60 per cent of our orders are filled out of stock within 48 hours.

In the setting of the production program, the sales department is not consulted. The sales department knows very little as to what quantity of sizes and styles it is really going to sell during a season. We have been able to assist the sales department by an analysis of our past shipments and by a study of business conditions that directly or generally affect us. In this way, the production department has in a sense set the quota for the sales.

As for the operation of the control system, the production manager has studied the capacities of the various departments and the units in those departments. He knows from the charts and records just where each department and unit stands in the amount of work ahead. Accordingly when an additional order is placed he makes the necessary additions to his records and sets the production schedule for it. Each department is scheduled by specific dates. Each unit in the department is scheduled about a week in advance. From the hourly and daily reports the production manager is able to follow the schedules and see that promises are kept.

Hugo Diemer.[6] The writer has visited many plants in recent years, and has gone over their methods of production control. The outstanding point, that all of us have to learn from this paper is that control of production with a minimum of investment in inventories is today not a thing to be worked toward, but a thing that is actually being practiced. Programming, planning of material, plans of operation, predetermination of work assignments, and all these other factors and statistics make this work much simpler than it was years ago. Further, the production budget, financial budget, and sales quota are practical and have far more close coordination than ever before.

W. R. Clark.[7] F. H. Calhoun, production control manager of the Goodyear Tire & Rubber Company, presented a paper at the Rochester meeting which contained several things that could have been embodied in the present paper. The thing of interest was that a rubber industry had worked out a scheduling system which, in many respects, could have been taken bodily and put into a brass mill. Mr. Calhoun said, in effect, that the various functions essential to production control include ordering and control of productive materials, the issuance of schedules, the dispatching of materials through the different processes, the stocking of raw and finished materials, and transportation and shipping. The function of the production-control department at the present time begins with the ordering of the materials required in the production of the various products manufactured. A yearly estimate is developed by the sales department, which outlines the probable requirements for each product manufactured by the company. This estimate is revised monthly to meet changing conditions in sales demands. Occasionally sales increases or decreases on certain products may largely exceed previous plans. The factory decides whether the tentative program is possible. The production-control division regulates the inventory on all productive materials. From the above tentative production schedule, a purchasing budget of materials is prepared.

Every one of those statements could be put bodily into the present paper, covering the control we are using in a brass mill today. It is very interesting that the rubber industry so closely parallels our efforts on a material which is manufactured in a somewhat different way.

In the rubber industry the process is a semi-continuous process. Most material started in process at the beginning of the week is finished before the end of the week. In the manufacture of brass, however, frequently materials are in process two, three, and four weeks, because in some cases there are hundreds of operations performed, particularly on smaller sizes. A large number of alloys are used. There are a large number of rolling or drawing operations, a large number of heat treatments, all

[4] U. S. Aluminum Co., Massena, N. Y.

[5] American Metal Cap Co., 2 Summit St., Brooklyn, N. Y.

[6] LaSalle Extension University, Chicago, Ill. Mem. A.S.M.E.

[7] General Works Manager, Bridgeport Brass Co., Bridgeport, Conn. Mem. A.S.M.E.

of which take time. There are a great many varieties of hardness or softness also, and all of these present a wide variety in the sizes, gages, widths, and lengths, a multitudinous amount of detail which makes proper scheduling control in the factory extremely difficult.

R. E. Flanders.[8] The writer's company manufacturers four or five different machine tools, and monthly determines how many units a week it shall build of those products. The rough-stock inventory, the size of the lots of work in process, and the finished-parts inventory are all determined on these standing orders, based on the output per week that has been set for that monthly period.

Every three months we go over the predetermined cycle or orders for parts in the shop. At some predetermined date in each three-month period an order is written out and put into the shop for each particular part in that program. That part may go into one, two, three, four, or five of the various machines we manufacture. It may go into one once, in others twice, and in others not at all. In any event, the number of pieces that are going to be required for the rate of production set at that time is determined quite definitely.

When the time comes to put orders for the parts into the shop, the stock clerk who makes out the order goes to the stockroom and counts the number of pieces in the bins. For the given rate of production on all machines manufactured there should be a certain number of pieces in the bins at that time. If there is more than that number of pieces, the amount of the shop order is decreased by the amount of excess. If less, the shop order is increased by the amount of the deficit. The lot of work goes through the shop, is finished at the predetermined time, and goes into the bin.

The number of parts that should have been in the bin when the count is made is such that when the new lot arrives in the bin it should find a half-lot in reserve waiting for it. In other words, we carry half of a three months' supply as a permanent margin. That reserve runs up and down with the predetermined schedule. We depend on the half-lot in reserve to enable us to change the rate of production at any time without having to wait for the three months' schedule to run its course and come around again.

Our rejections are expected to occur before they get to the stockroom, not afterward. The half-lot is a sort of safety valve for contingencies. In the same way, the purchasing agent is supposed to keep in reserve a half-lot of raw materials. This includes castings, for instance, or a half-lot supply of bar stock and similar materials, so that there always is a reservoir of a half-lot to take care of spoilages, sudden increases in production, etc. We thus are free to take care of emergencies, and also to change the schedule within limits at any time and still run the shop on standing orders.

Not a piece of paper passes between the production office and the purchasing department or the stock clerk, other than the monthly statement of the number and kind of machines we are to build per week. We have done away with stock records, and we run on standing orders instead of making a special case of every item of production in the shop.

This plan has proved exceedingly successful with a small volume of production, when difficulties would be most apt to appear. We live in the hope of applying it before long to a much larger volume.

[8] Jones & Lamson Machine Co., Springfield, Vt. Mem. A.S.M.E.

David B. Porter.[9] One of the problems mentioned by the author is the coordination of sales with production. We have found that there is no coordination whatsoever until a sales schedule is finally worked out in harmony with the mill's capacity to produce. After the schedule is made, it can be charted by means of a Gantt chart. The sales department then can watch by means of this chart the exact progress of manufacturing; and furthermore, the amounts of orders for the different lines of goods are clearly visible on this chart.

In a certain case when we first drew up the chart, some lines were oversold half a year ahead, and other lines were not sold more than a few weeks ahead, showing a very unfavorable condition. The charts were blueprinted weekly and sent to the sales department, where they were used to direct sales in accordance with the schedules shown.

Arthur Brewer. Mr. Johnston and Mr. Kushnick both spoke of the method of promising deliveries within a particular week and on a specific day. We use both methods. If the customer does not specifically request a date, we promise to the week. We call it a "schedule promise." When he particularly asks what day the goods will be shipped, we give the day, which we call a "firm promise." These are handled with a little more follow-up than the "schedule promises."

In regard to the percentage of kept promises, our "schedule promises" are fulfilled between 90 and 95 per cent. Our "firm promises" are probably kept to nearly 99 per cent. I just last week authorized the expenditure of a sum of money to give the mill foremen a dinner. Two mills had just had a competition. The foremen of the mill first to go ten weeks without a broken promise were to have a dinner. One mill had gone 21 weeks and the other had gone 15 weeks. They went so far beyond the goal set that we gave them both a dinner.

Mr. Kushnick also said that they did not consult the sales department in making up schedules. We did not use to do this. We used to make the schedule up in the production office, but I was convinced that it could be improved. The production men are usually pessimistic with regard to the ability of the sales department to secure orders, while on the other hand the sales department is very optimistic. I believe the best way is to get your optimists and pessimists together and discuss the question. Then, I think, you can strike a closer, truer production schedule than when you allow either one or the other to set it.

Papers have been delivered this morning in regard to the matter of setting budgets and how they can be controlled. We have had budgets for a good many years. In regard to the sales budget, the tendency has been with the sales department to say when business is poor, "What are we going to do—there aren't any orders?" but when business is good—"Aha, see us! See how we bring in orders," and then hound the production department to get them out. By getting together to discuss the matter the sales department has realized much more intimately the necessity of getting orders for certain lines to make a well-rounded-out production and to keep each unit producing. Of course, business conditions control this more or less, but they can do something to help out under all conditions.

I am glad to hear the various statements in regard to the use of Gantt charts. We have not used many charts in connection with the sales department, because our men have been educated to read figures rather than charts. We have found that we can get our idea across better by the use of figures than we could by the use of charts.

[9] New York University, New York. Mem. A.S.M.E.

# Some Essential Principles for Budgetary Control

By HAROLD VINTON COES,[1] CHICAGO, ILL.

*This paper presents in condensed form many of the essential principles for the application of budgeting to a business and the effective means for control. Some of the means for securing budgetary control are shown in charts and statements of the following: (1) fundamental operating relationships, (2) comparative results of operation for different sales volumes, (3) manufacturing expense budget, (4) indirect labor control, (5) sales and production coordination, (6) sales quota, (7) department quota, (8) comparison of operating ratios.*

THIS paper is presented with the idea of endeavoring to reduce to as few words as possible many of the essential principles for the application of budgeting to a business, and the effective means for control.

*Coordinated Intelligence*

Utilize those methods that will combine effectively the coordinated intelligence of the entire organization behind a predetermined plan.

*Analysis*

Analyze past operations, past performance, past expenditures, sales, etc. in fact all those phases of the business that it is proposed to budget.

*Synthesis*

Build up from the facts developed by analysis the trends and tendencies of the past.

*Judgment*

By rational judgment ascertain and isolate those factors that will influence the course of the business in the future.

*Initial Control*

Ascertain the places where control can be most effectively obtained initially in the method, procedure, recording, and performance.

*Operating Ratios*

There is no uniform set of standard ratios expressing the various fundamental relationships between expenses and sales, manufacturing expense and cost of sales, etc. These must be determined for each individual business from the study of past records, and then checked against such ratios for the industry or important units in the industry as can be obtained. The application of these previously determined ratios then to the various items of expense in various divisions of the business will constitute the budgeted expense items.

*Relationship of Phases in Business*

Develop the fundamental relationship between the various phases of the business, such as ratio of manufacturing expense to net production, to net sales, distribution expense to net sales, and the like.

[1] Vice-President and General Manager, Belden Manufacturing Company. Vice-President and Chairman of Finance Committee, A.S.M.E.

Contributed by the Management Division and presented at the Annual Meeting, New York, December 5 to 8, 1927, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. For discussion see p. 10.

*Adequate Accounting*

A prerequisite to successful budgeting is adequate accounting and statistical records, for budgeting is dependent upon all the recorded data of regular routine wherein past performance may be determined and future possibilities outlined.

*Organization*

Realign the duties of the organization so that duties and functions are logically grouped.

*Corelationship of Activities*

Budgetary control correlates the activities of the various functions of the business through executive control to prevent over, undue, or lack of emphasis on some important phase of the business.

FUNDAMENTAL OPERATING RELATIONSHIPS

| Ratio | Year 1922 | 1923 | 1924 | 1925 | 1926 | Max. or Min., per cent |
|---|---|---|---|---|---|---|
| | Per cent | | | | | |
| Cost of Sales / Net Sales | 79.9 | 79.2 | 78.1 | 77.8 | 80.1 | 75 |
| Mfg. Expense (Burden) / Net Production | 29.4 | 24.0 | 26.8 | 26.1 | 23.5 | 22 |
| Mfg. Expense / Net Sales | 24.5 | 22.0 | 24.3 | 24.7 | 20.2 | 20 |
| Raw-Material Inventory / Net Production | 40.1 | 42.0 | 41.9 | 39.8 | 38.9 | 35 |
| Process Inventory / Net Production | 30.1 | 32.0 | 31.0 | 29.9 | 29.2 | 26 |
| Direct Material / Net Sales | 37.5 | 35.2 | 37.2 | 38.5 | 39.1 | 35 |
| Direct Labor / Net Sales | 23.4 | 22.8 | 20.9 | 21.7 | 22.0 | 20 |
| Indirect Labor / Direct Labor | 47.0 | 46.5 | 46.1 | 45.8 | 45.2 | 40 |
| Finished-Goods Inventory / Net Sales | 10.8 | 10.4 | 10.1 | 10.5 | 10.0 | 10 |
| Total Inventory / Net Sales | 24.3 | 24.0 | 23.8 | 24.2 | 23.0 | 20 |
| Fixed Expense / Total Mfg. Expense | 28.1 | 28.3 | 27.9 | 27.2 | 27.5 | 25 |
| Working Capital / Net Sales | 35.1 | 34.8 | 35.5 | 34.2 | 33.1 | 30 |
| Gross Profit / Net Sales | 21.1 | 20.9 | 21.9 | 22.2 | 19.9 | 25 |
| Selling Expense / Net Sales | 10.9 | 11.0 | 11.4 | 12.2 | 12.5 | 11 |
| Net Profit / Net Sales | 4.3 | 4.7 | 5.1 | 5.5 | 3.9 | 5 |

*The Budget and Executives*

The budget can in no way replace skilful executives, but in their hands it is an exceedingly useful tool for modern management.

*Flexible Standards*

The expression of results for the various phases of the business, for the departments, subdivisions, etc. should be in such terms that they are suitable to the various elements, yet flexible enough to permit ready adjustment to ever-changing conditions.

*Determination of Standards*

Carry the analysis far enough back over a sufficient period so that the law of averages, the swings or cycles, trends and tendencies can be fully developed; correct for those influences

COMPARATIVE RESULTS OF OPERATIONS FOR DIFFERENT SALES VOLUMES[1]

| Sales, in thousands of dollars | 500 | 600 | 700 | 800 | 900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Per cent | | | | | | | | | | | | | | | |
| Sales | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Materials | 40.3 | 39.4 | 38.5 | 37.8 | 37.2 | 36.7 | 36.7 | 36.7 | 36.7 | 36.7 | 36.7 | 36.4 | 36.1 | 35.8 | 35.5 | 35.2 |
| Direct labor | 28.0 | 27.5 | 27.0 | 26.5 | 26.0 | 25.5 | 25.5 | 25.5 | 25.5 | 25.5 | 25.5 | 25.0 | 24.5 | 24.0 | 23.5 | 23.0 |
| General factory expense | 20.0 | 19.0 | 18.0 | 17.0 | 16.5 | 16.0 | 15.5 | 15.0 | 14.5 | 14.0 | 13.5 | 13.0 | 13.0 | 13.0 | 13.0 | 13.2 |
| Cost of sales | 88.3 | 85.9 | 83.5 | 81.3 | 79.7 | 78.2 | 77.7 | 77.2 | 76.7 | 76.2 | 75.7 | 74.4 | 73.6 | 72.8 | 72.0 | 71.2 |
| Gross profit on sales | 11.7 | 14.1 | 16.5 | 18.7 | 20.3 | 21.8 | 22.3 | 22.8 | 23.3 | 23.8 | 24.3 | 25.6 | 26.4 | 27.2 | 28.0 | 28.8 |
| Selling expenses | 8.0 | 7.7 | 7.5 | 7.3 | 7.1 | 7.0 | 6.9 | 6.8 | 6.7 | 6.6 | 6.5 | 6.4 | 6.3 | 6.2 | 6.1 | 6.0 |
| Selling profit | 3.7 | 6.4 | 9.0 | 11.4 | 13.2 | 14.8 | 15.4 | 16.0 | 16.6 | 17.2 | 17.8 | 19.2 | 20.1 | 21.0 | 21.9 | 22.8 |
| Administrative expense | 10.0 | 9.0 | 8.0 | 7.0 | 6.5 | 6.0 | 5.9 | 5.8 | 5.7 | 5.6 | 5.5 | 5.4 | 5.0 | 5.0 | 5.0 | 5.0 |
| Operating profit | 6.3[2] | 2.6[2] | 1.0 | 4.4 | 6.7 | 8.8 | 9.5 | 10.2 | 10.9 | 11.6 | 12.3 | 13.8 | 15.1 | 16.0 | 16.9 | 17.8 |

[1] By Bigelow Kent Willard & Co. [2] Loss.

Form [illegible]

SCHEDULE______

## MANUFACTURING EXPENSE

______________ DEPARTMENT

MONTH______________192__

| Acct No. | NAME | This Month | Per $100 Prod. | Last Month | Per $100 Prod. | Budget | Per $100 Prod. | Cumulative Actual | Per $100 Prod. | Cumulative Budget | Per $100 Prod. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 321 | Insurance | | | | | | | | | | |
| 322 | Taxes | | | | | | | | | | |
| 323 | Rentals | | | | | | | | | | |
| 324 | Depreciation | | | | | | | | | | |
| 330 | Development | | | | | | | | | | |
| 340 | Power Plant Oper. Labor | | | | | | | | | | |
| 350 | Power Plant Supplies | | | | | | | | | | |
| 360 | Power Plant Inc. Oper. Exp. | | | | | | | | | | |
| 370 | Power Plant Maintenance | | | | | | | | | | |
| 390 | Power, Heat & Light Purchased | | | | | | | | | | |
| 410 | Maintenance Land | | | | | | | | | | |
| 420 | Maintenance Buildings | | | | | | | | | | |
| 430 | Maintenance Structures | | | | | | | | | | |
| 440 | Maintenance Heat. Vent. Wire. | | | | | | | | | | |
| 450 | Repairs to Mach. Elec. Furn. | | | | | | | | | | |
| 451 | Replacements and Improvements to Mach. Elec. Furniture | | | | | | | | | | |
| 480 | Maintenance Automobiles | | | | | | | | | | |
| | TOTAL | | | | | | | | | | |
| | Budget Correction for Variation in Productive Labor | | | | | | | | | | |
| | Corrected Total | | | | | | | | | | |
| | % Actual Expense to Budget Expense | | | | | | | | | | |

MANUFACTURING-EXPENSE SCHEDULE[1]

201 Factory Supervision
202 Foreman & Assistants
203 Inspectors
210 Clerical Labor
211 Cost & Payroll Dept.
212 Production Dept.
213 Employment
220 Other Labor
221 Janitors, Watchmen & Elev.
226 Machine Set-Up
227 Overtime—Bonus
228 Allowances
229 Idle Time
230 Development Engineering
231 Plant Engineering
241 Fuel Consumed—Gas
242 Water
243 Lubricants
244 Non-Durable Small Tools
245 Factory Office Supplies
246 Miscellaneous Shop Supplies
247 Steam
250 Unassignable Frt.-Exp.
260 Employees' Service
270 Accident Compensation
281 Defective Workmanship
282 Defective Workmanship Cr.
283 Other Losses Due to Errors
291 Purchasing Dept.
292 Stores—Rec. Department
293 Finished Stock Department
294 Shipping Department
295 Labeling Department
96 Rewind Department
301 Rearrangement of Equip.
303 Traveling Expenses
305 Garage
306 Shop Electric Plant
307 Instruction of Apprentices
308 Unassignable Testing Expense
309 Other Manufacturing Expense
310 Belden Spool Expense
311 Foreign Spool Expense
312 Laboratory
313 Inter-Plant Expense
314 Assn. Dues and Memberships

[1] Two similar preceding forms care for items 201–314 as listed above.

SALES AND PRODUCTION—COMPARISON FOR INVENTORY CONTROL AS OF APRIL 30, 1927

| Products or lines of merchandise | No. | Est. net sales for May | Net sales for April | Net. sales for April last year | In stock May 1 at selling prices: Standards | In stock May 1 at selling prices: Specials | Total inventory at selling prices | Max. point this year | Inventory gain or loss in month | Inventory quota Apr. 30 at selling prices | May 1, value of orders on books | Net production for April at selling prices | Net production April, 1926, at selling prices |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ............ | 1 | ..... | ..... | ........ | ........ | ........ | ........ | ..... | ........ | ........ | ........ | ........ | ........ |
| ............ | 2 | ..... | ..... | ........ | ........ | ........ | ........ | ..... | ........ | ........ | ........ | ........ | ........ |
| ............ | 13 | ..... | ..... | ........ | ........ | ........ | ........ | ..... | ........ | ........ | ........ | ........ | ........ |
| ............ | 14 | ..... | ..... | ........ | ........ | ........ | ........ | ..... | ........ | ........ | ........ | ........ | ........ |

(All figures in thousands of dollars) Total for High Month.........

that were purely accidental, so that representative standards may be developed.

*Segregation of Costs*

Segregate all items of expense or cost into three groups:

1 Fixed or non-variable
2 Semi or partially variable
3 Full variable.

*Break-Even Point*

Develop the break-even points (points at which no profit or loss is sustained) for the expenses as budgeted for the various departments, and the corresponding volume of sales per class of product.

*Production Capacities*

Regardless of sales volume, determine the production capacity of the plant and break this down by departments, by sections, in well-balanced relationships. Determine it also by classes of product.

*Relationship Between Productive Capacity and Sales Volume*

Through the market surveys determine the minimum volume at those price levels that the market will take up, which will absorb the greatest proportion of potential productive capacity.

*Product Demand*

Budgeting is again dependent upon a knowledge and relationship between:

*a* Demand for the given product and demand for the product of the entire industry
*b* Demand for the individual product and its relationship to the demand for similar articles similarly marketed
*c* The purchasing power for which the demand can be sustained.

*Budget Period*

Cover the longest period with the minimum business hazard. Usually the period can be the longest for those businesses having the least hazard, and must be shortened as the business hazard increases. Its determination is fundamental and is largely contingent upon several factors, such as:

*a* The business risk
*b* The stability of the market
*c* The method of financing, production and inventories
*d* The schedule period of production
*e* The duration of the reporting and accounting period
*f* The adequacy of statistical information as to past performance and transactions
*g* The merchandising inventory turnover period
*h* The seasonal or periodical demands and fluctuations.

*Revision of Budget*

Budgets should be checked, compared, and revised monthly.

*Control of Expense*

Control can be obtained by frequent comparisons—not less than once a month—between actual and budgeted expenses, the budget of course adjusted for the legitimate expansion or contraction in sales volume or production that has occurred contrary to the predetermined budget for the period.

*Limits*

The budgets as adopted constitute the standards of performance for the period determined, and establish limits for the expenditures of each division and section of the business, but should not be exceeded without permission from the properly constituted authority.

*Forecasts*

Forecast all those expenditures, be they capital outlays or expense items, that it is proposed to control by budgets, or that will affect the phase or phases of the business to be controlled by budget procedure.

*Preparation of and Responsibility for Budget Estimates*

The source of information should be from the logical divisions of the business, and the responsibility for the origin and accuracy should be lodged with those charged with the responsibility for the performance of the aforesaid divisions or sections thereof.

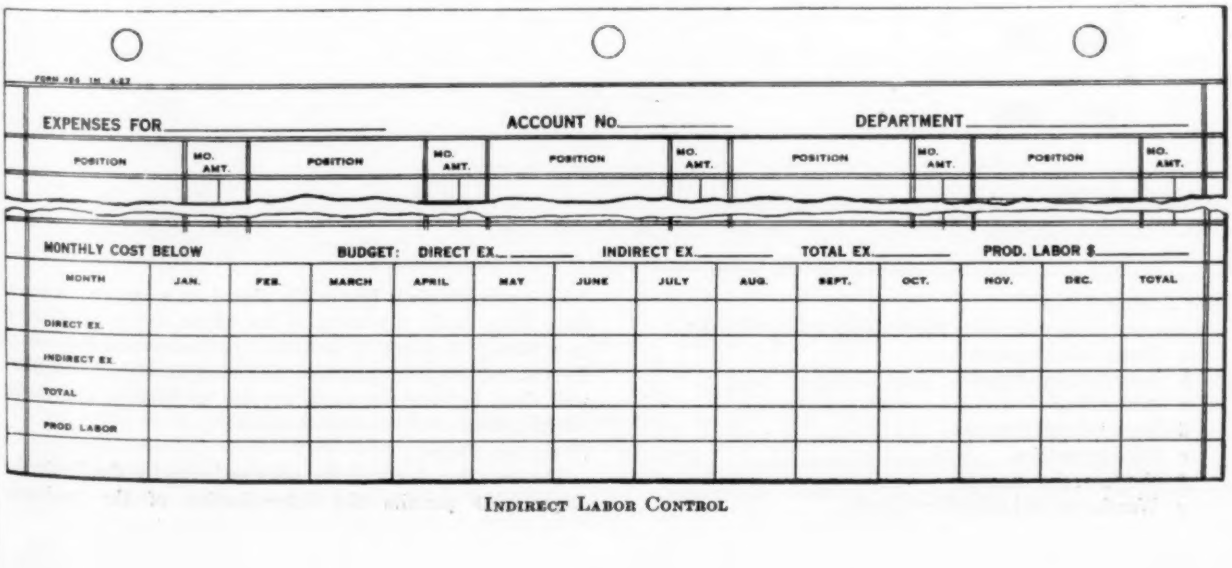
*The Sales Estimate or Forecast*

This is based upon information from three sources:

1 The amount and character of previous sales—analyzed
2 The present and future market conditions, the trade situation—market analysis
3 The executive plans, policies, and administrative expense of the business.

*Balancing of Production and Sales Demand*

Proper sales forecasting coupled with adequate inventory control permits the application of the principle of balancing production with sales demand.

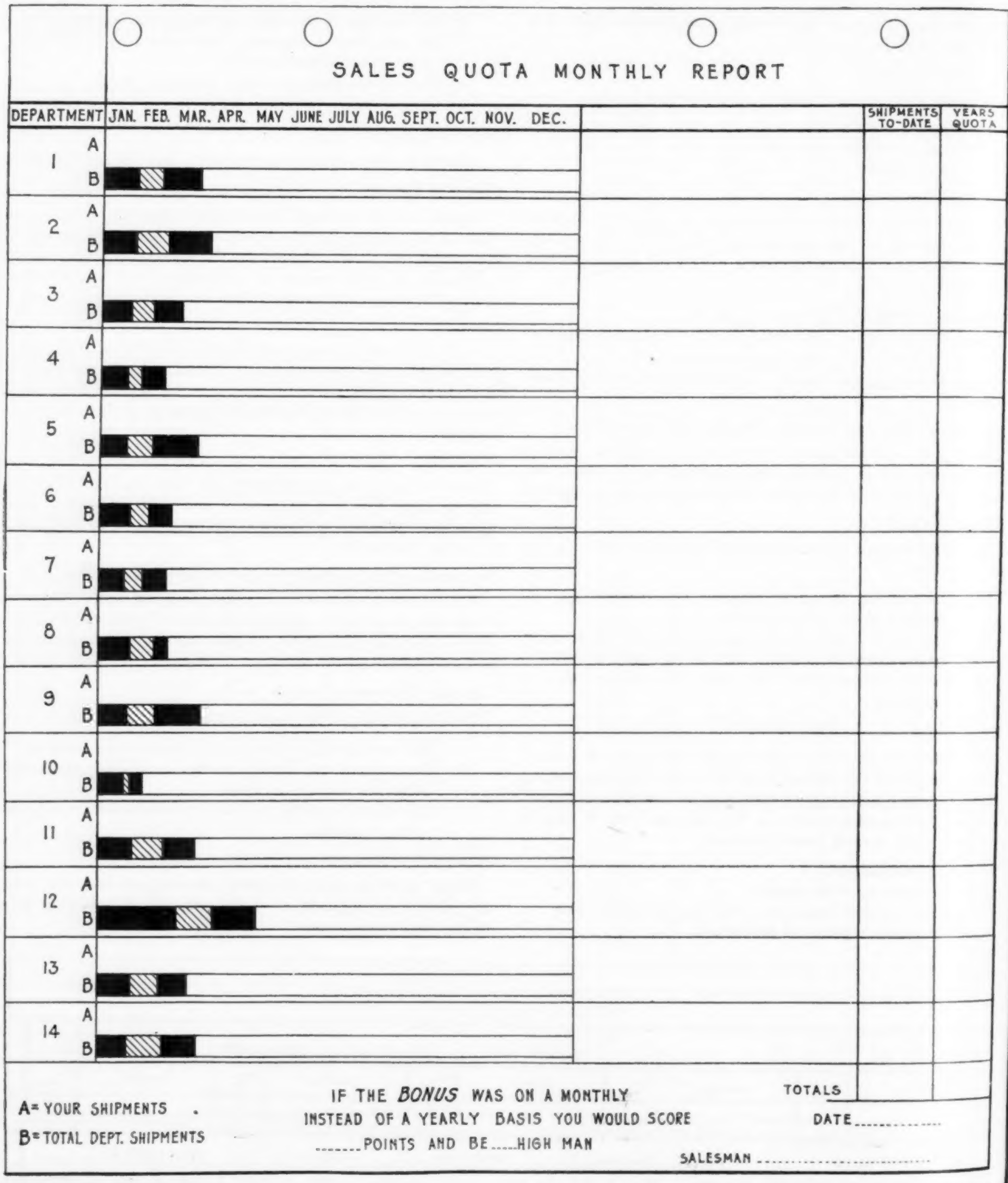

EXPENSES FOR ____ ACCOUNT No. ____ DEPARTMENT ____

| POSITION | MO. AMT. | POSITION | MO. AMT. | POSITION | MO. AMT. | POSITION | MO. AMT. | POSITION | MO. AMT. |
|---|---|---|---|---|---|---|---|---|---|

MONTHLY COST BELOW BUDGET: DIRECT EX. ____ INDIRECT EX. ____ TOTAL EX. ____ PROD. LABOR $ ____

| MONTH | JAN. | FEB. | MARCH | APRIL | MAY | JUNE | JULY | AUG. | SEPT. | OCT. | NOV. | DEC. | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DIRECT EX. | | | | | | | | | | | | | |
| INDIRECT EX. | | | | | | | | | | | | | |
| TOTAL | | | | | | | | | | | | | |
| PROD. LABOR | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

Indirect Labor Control




*Sales Expense Budget*

It is aimed to secure proper relationship and control of:

- *a* Direct sales expense
- *b* General sales expense
- *c* Advertising
- *d* Branch-house expense
- *e* Sales promotion
- *f* Foreign sales expense
- *g* Warehouse and shipping expense.

Undue emphasis is frequently placed on some one or two of these items to the detriment of the others, and to the business as a whole. Advertising and sales promotion are frequent offenders. A properly prepared and considered budget will reveal these facts, show which are out of balance, and permit bringing the several items into balance.

*Production Budget*

The breaking down of the sales estimate by the Production Department permits the determination of the production

DEPARTMENT QUOTA MONTHLY REPORT

| DEPARTMENT | JAN. | FEB. | MAR. | APR. | MAY | JUNE | JULY | AUG. | SEPT. | OCT. | NOV. | DEC. | SHIPMENTS TO-DATE | YEAR'S QUOTA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 120,000 | 240,000 | 370,000 | 490,000 | 615,000 | 735,000 | 812,000 | 932,000 | 1,052,000 | 1,182,000 | 1,317,000 | 1,442,000 | | |
| 2 | 65,000 | 125,000 | 185,000 | 235,000 | 290,000 | 340,000 | 382,000 | 467,000 | 557,000 | 657,000 | 752,000 | 837,000 | | |
| 3 | 65,000 | 135,000 | 210,000 | 275,000 | 340,000 | 400,000 | 447,000 | 517,000 | 597,000 | 682,000 | 762,000 | 832,000 | | |
| 4 | 15,000 | 30,000 | 50,000 | 65,000 | 80,000 | 93,000 | 100,000 | 115,000 | 135,000 | 160,000 | 180,000 | 200,000 | | |
| 5 | 20,000 | 40,000 | 70,000 | 90,000 | 115,000 | 135,000 | 145,000 | 165,000 | 195,000 | 225,000 | 250,000 | 270,000 | | |
| 6 | 30,000 | 57,000 | 84,000 | 106,000 | 126,000 | 146,000 | 163,000 | 191,000 | 221,000 | 277,000 | 327,000 | 370,000 | | |
| 7 | 10,000 | 20,000 | 40,000 | 60,000 | 80,000 | 100,000 | 115,000 | 135,000 | 156,000 | 181,000 | 201,000 | 221,000 | | |
| 8 | 30,000 | 50,000 | 70,000 | 85,000 | 95,000 | 100,000 | 110,000 | 140,000 | 190,000 | 260,000 | 330,000 | 380,000 | | |
| 9 | 22,000 | 42,000 | 62,000 | 79,000 | 96,500 | 113,500 | 120,500 | 147,500 | 170,500 | 199,500 | 226,000 | 251,000 | | |
| 10 | 16,500 | 24,000 | 32,500 | 42,500 | 57,500 | 77,500 | 112,500 | 142,500 | 187,500 | 237,500 | 287,500 | 313,000 | | |
| 11 | 15,000 | 30,000 | 48,000 | 63,000 | 75,000 | 85,000 | 90,000 | 110,000 | 129,500 | 149,500 | 169,500 | 186,500 | | |
| 12 | 23,000 | 38,000 | 48,000 | 58,000 | 63,000 | 68,000 | 73,000 | 83,000 | 93,000 | 113,000 | 128,000 | 138,000 | | |
| 13 | 5,000 | 9,000 | 15,000 | 20,000 | 24,000 | 28,000 | 31,000 | 36,000 | 41,000 | 47,000 | 52,000 | 57,000 | | |
| 14 | 4,000 | 8,000 | 13,000 | 17,000 | 22,000 | 27,000 | 30,000 | 34,000 | 38,500 | 43,500 | 47,500 | 51,500 | | |
| 15 | 440,500 | 848,000 | 1,297,500 | 1,685,500 | 2,079,000 | 2,448,000 | 2,734,000 | 3,215,000 | 3,769,000 | 4,419,000 | 5,029,500 | 5,549,000 | | |
| TOTALS | | | | | | | | | | | | | | |

DATE ................ 1927

estimates in total, except for goods made to special order. Ordinarily it is impractical to budget in advance special order production per se.

The principle of scheduling is then used to insure production in sufficient quantity at the proper time to satisfy the estimated sales demand, which is predicated upon:

*a* Operation analysis—from specifications of product

*b* Schedule of productive equipment with capacity per unit.

This may show that:

*a* Sales forecast exceeds present productive capacity under normal operation

*b* Sales forecast is less than present productive capacity under normal operation

*c* Sales forecast approximates present capacity under normal capacity,

and will necessitate reconciliation of either one or the other, depending upon the financial program.

This brings in inventory control, since it is usually impossible to so accurately forecast sales demand and schedule production as to have the two so synchronized as to accurately meet sales demand.

Excessive production beyond immediate sales demand runs up the inventory and ties up working capital. Inadequate production causes poor service to customers and lost sales, and consequently lost income. Hence adequate inventory control is of prime importance.

*Balanced Inventory*

Properly apportioned and balanced inventories are then a prerequisite to satisfactory budget operation, and these are brought about by adequate and comprehensive budgetary control.

various classes of product. By then stating the dollar volume in the sales estimates, adjusting for cost of sales, and applying the labor ratios, a fairly approximate labor budget can be set up.

By using similar ratios for the relationship of direct to indirect labor, the indirect labor budget can be similarly prepared.

*Manufacturing-Expense Budget*

Where centralized production and standardized goods for stock are not the rule, probably the most practical method of dealing with the manufacturing expense is by the application of the principle of standard overhead or burden rates. Here a reserve is set up and over-absorption of burden during peak or overnormal operations is credited to the reserve, and during dull seasons, when operating at less than normal capacity, the deficiency is debited from the reserve, the whole being set so as to balance out for the year's operation.

MONTHLY COMPARISON OF OPERATING RATIOS

| RATIO | JAN. | FEB. | MAR. | APR. | MAY | JUNE | JULY | AUG. | SEPT. | OCT. | NOV. | DEC. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Net Sales Billed to Quota | | | | | | | | | | | | |
| Cumulative | | | | | | | | | | | | |
| Distribution Expense to Budget | | | | | | | | | | | | |
| Cumulative | | | | | | | | | | | | |
| Administrative Expense to Budget | | | | | | | | | | | | |
| Cumulative | | | | | | | | | | | | |
| General Expense to Expense absorbed | | | | | | | | | | | | |
| Cumulative | | | | | | | | | | | | |
| Manufacturing Expense to Budget | | | | | | | | | | | | |
| Cumulative | | | | | | | | | | | | |
| Manufacturing Expense to Expense Absorbed | | | | | | | | | | | | |
| Cumulative | | | | | | | | | | | | |
| Factory Operating Capacity to Normal | | | | | | | | | | | | |
| Cumulative | | | | | | | | | | | | |

*Material Budget*

Since the principle of balance of stores is applied satisfactorily for the finished goods inventory control, the same principle can be applied to balance of stores records for raw material.

*Labor Budget*

This is the most difficult budget to prepare, particularly where goods made to order are a large proportion of the total production, since operations and combination of operations vary over wide ranges. The principle of standardized operations is applied, and where this is done one hundred per cent the preparation of the labor budget ceases to be a difficult matter.

Frequently an approximate control can be obtained by using predetermined ratios of direct labor cost in the cost of sales of

For control purposes the actual expenses should be compared, not only with the normal budget but also with the normal budget adjusted to what it would be for the actual capacity operations. Under these conditions control can be effectively obtained.

*Plant and Equipment Budget*

This is to prevent:

1 Overexpansion
2 Force careful considerations of capital layouts
3 Preserve proper relationship between retirements, replacements, maintenance, and depreciation reserves
 a Repairs charged to current expense—standard maintenance and standard maintenance budget

*b* Betterments (improvements) and additions are set up in the capital budget.

This budget would then show:

1 The estimated cost of new equipment installed and in place
2 The depreciation and anticipated repairs on new equipment
3 The depreciation and anticipated repairs on present equipment.

*General and Administrative Expense Budgets*

These to cover such broad classifications as:

*Financial Budget*

This is set up for the correlation of income and expenditures:

*a* An estimate of cash requirements, predicated upon the programs as set forth in the preceding budets
*b* Estimate of cash receipts. This is predicated upon:
  1 A relationship of sales to collections
  2 Other sources
  3 Bank loans—with program therefor.
*c* An estimate of cash disbursements:
  1 Material purchases (accounts payable)
  2 Factory payroll

SCHEDULE ________

________ DEPARTMENT

ADMINISTRATION EXPENSES. MONTH ________ 192__

| ACCT. NO. | NAME | THIS MONTH | LAST MONTH | BUDGET | CUMULATIVE ACTUAL | CUMULATIVE BUDGET |
|---|---|---|---|---|---|---|
| | Salaries: | | | | | |
| 21 | Officers-Dept. Heads | | | | | |
| 23 | Clerical Employees | | | | | |
| 25 | Treasury Dept. | | | | | |
| 26 | Gen'l. Acctg. Dept. | | | | | |
| 27 | Other Expenses | | | | | |
| 30 | Rent,Lt.Ht.Exec. Offices | | | | | |
| 32 | Office Equip.Rep & Repl. | | | | | |
| 34 | Traveling & Entertainment | | | | | |
| 36-37 | Tel. & Telg. Expenses | | | | | |
| 38 | Stat'y.-Office Supplies | | | | | |
| 39 | Donations | | | | | |
| 41 | Depreciation | | | | | |
| 43 | Legal-Consulting | | | | | |
| 45-47 | Other Expenses | | | | | |
| | TOTAL | | | | | |
| | NON-DEPT'L. EXPENSE | | | | | |
| 147 | Corporate Taxes | | | | | |
| 148 | Patent Expenses | | | | | |
| 149 | Disc. Exp on Bond Issue | | | | | |
| 150 | Accrual against Poss.Loss | | | | | |
| 152-154 | Unabsorbed Trans. | | | | | |
| 156 | Warehouse Expenses | | | | | |
| | TOTAL | | | | | |
| | MISCELLANEOUS INCOME | | | | | |
| 161 | Interest on Notes-A/C Rec. | | | | | |
| 162 | Miscellaneous | | | | | |
| 163 | Return on Investment | | | | | |
| 164 | Purchase Discount | | | | | |
| 165 | Belden Spool Profit | | | | | |
| | TOTAL | | | | | |
| | CHARGES TO INCOME | | | | | |
| 171 | Interest on Notes Pay. | | | | | |
| 172 | Interest on A/C Pay. | | | | | |
| 173 | Interest on Bonds | | | | | |
| 174 | Sales Discount | | | | | |
| | TOTAL | | | | | |

ADMINISTRATION-EXPENSE SCHEDULE

*a* Executive
*b* Service or auxiliary departments
*c* Financial
*d* Non-departmental or corporate expense,

and these are predicated upon:

1 A proper main classification logical for the organization as set up
2 The incidence of these expenses and the responsibility for their origin and supervision
3 Sufficient sub-classifications to enable detection of variations and permit the focusing of responsibility.

3 Factory overhead expense (manufacturing expense)
4 Distribution expense (sales expense)
5 General and administrative expense (executive)
6 Non-departmental (corporate)
7 Capital account (new equipment, plant, etc.).

*The Forecast Balance Sheet*

1 Assets and liabilities
2 Profit and loss.

These two statements, then, when compared with the actual results of operation, show what the effect has been of the individual budgets and quotas on the operation of the business as

a whole, and where these have fallen below or exceeded actually the predetermined balance sheet and profit-and-loss statement.

From this master budget and individual budgets the executives can then determine why the predetermined programs fail to be realized and can apply the corrective measures required to bring them in balance. This may result in revisions of many of the individual budgets to bring this about.

*Reports*

Suitable reports should be set up giving estimated forecasts of predetermined budgets compared with actual results:

These reports showing the comparison between the estimated or forecast performance are taken as standard, and the actual performance renders it possible for the executives responsible to enforce the budget and keep operations correlated and in balance.

They also serve to show what plans must be made for the future for financing, for production, for sales expansion or curtailment and the future plant requirements.

Some of the means for securing budgetary control are shown in the accompanying statements and charts:

1 Fundamental operating relationships

SCHEDULE________

________ DEPARTMENT

DISTRIBUTION EXPENSES. MONTH________192__

| ACCT. NO. | NAME | THIS MONTH | LAST MONTH | BUDGET | CUMULATIVE ACTUAL | CUMULATIVE BUDGET |
|---|---|---|---|---|---|---|
| | Salaries: | | | | | |
| 51 | Officers-Dept. Heads | | | | | |
| 53 | Advertising | | | | | |
| 54-57 | Selling Force, Sales Rec | | | | | |
| 58 | Terr. Correspondents | | | | | |
| 59 | Stenographers | | | | | |
| 60-61 | Sales Engr. | | | | | |
| 62-67 | Clerical Employees | | | | | |
| 68 | Foreign Dept. | | | | | |
| 69 | Credits & Collections | | | | | |
| 70-71 | Billing & Distr. Acctg. | | | | | |
| 73-76 | Traveling & Entertainment | | | | | |
| 77-78 | Telephone & Telegraph | | | | | |
| 79 | Postage | | | | | |
| 81 | Stat'y. & Office Supplies | | | | | |
| 84 | Office Equip. Rep & Repl. | | | | | |
| 85-91 | General Advertising | | | | | |
| 92-99 | Radio Advertising | | | | | |
| 92A-99A | Automotive Advertising | | | | | |
| 92E-99E | Electrical Advertising | | | | | |
| 101-103 | Catalogues General | | | | | |
| 101A-103A | Catalogues Automotive | | | | | |
| 101E-103E | Catalogues Electrical | | | | | |
| 101R-103R | Catalogues Radio | | | | | |
| 106 | Sales Commissions | | | | | |
| 107 | Losses due ro Errors | | | | | |
| 109 | Collections Fees | | | | | |
| 112-113 | Foreign Sales Expense | | | | | |
| 115 | Samples | | | | | |
| 117 | Depreciation | | | | | |
| 118-119 | Rent | | | | | |
| 120-121 | Other Expenses | | | | | |
| 126-135 | Newark Branch | | | | | |
| 136-145 | Cleveland Branch | | | | | |

Form 400 500 1-25-27

DISTRIBUTION-EXPENSE SCHEDULE

1 Showing relationship between production and inventory, including production, sales and inventories
2 Manufacturing expense
3 Labor
4 Purchases
5 Material
6 Sales
7 Sales expense
8 General and administrative expense
9 Balance sheet
10 Income statement
11 Operating-ratio comparisons
12 Maintenance control.

2 Comparative results of operation
3 Manufacturing-expense budget
4 Indirect labor control
5 Sales and production coordination
6 Sales quota
7 Department quota
8 Comparison of operating ratios.

NOTE: For some of the material for this paper the author wishes to acknowledge his indebtedness to "Budgetary Control," by J. O. McKinsey, "Organization and Budgetary Control in Manufacturing," by Fordham and Tingley, "Financial Handbook," by R. H. Montgomery, "Management's Handbook," by L. P. Alford, *Manufacturing Industries*, *Industrial Management*, and the American Management Association.

# Budgetary Control

By J. P. JORDAN,[1] NEW YORK, N. Y.

*In the influence held by a chief executive over the mentalities of his subordinates, whereby he secures from them the greatest possible producing effort, lies the real secret of his success. Many executives hold this influence by sheer personality. Others hold it by a combination of personality and the careful selection and provision of various schemes whereby the subordinates themselves are more or less automatically spurred on in their efforts.*

*It is a well-recognized fact that we are a nation of aggressive people; that we take business chances as a matter of course. The widespread interest in sports—golf, baseball, football, tennis, boxing, polo, etc.—is evidence of the sporting angles of the average American mind: the apparent evidence of a desire either to indulge in or to become interested in a game.*

*Budgetary control supplies to every one in any kind of a business institution a species of a game. The setting of quotas of performance and budgets of expense brings out a cool and calculating thought of the future and what it should yield. The daily watching of the current transactions becomes as fully absorbing as the watching of the electric score board of a World's Series game. A par has been set and must be beaten.*

*The psychological effect of budgetary control is its greatest asset, and in this feature alone it takes its place as perhaps the most valuable of all more or less mechanical management aids.*

THE type of management which pays strict regard to psychological effects in controlling the various operations of a business institution is almost invariably successful. While it is often said that since the war, management has been obliged to control in a manner different from that which obtained before the war, it is probably a fact that the most outstanding cases of successful management before the war were those which employed exactly the same methods as are successful today. Since the war, management in general has been forced to give far greater consideration to the human factors of business than before.

We have heard a great deal about "Golden Rule" management, cooperative management, committee management, legislative management, and all such types which have been more or less successful. If one would analyze the various-named types of management which have been used, it is believed that the final conclusion would be that the outstanding successes have been those where careful psychological analyses became the guide of the executives who composed the successfully managed business, rather than some specific form of management. It is somewhat immaterial as to the exact methods used in applying to a generous degree the results of careful consideration of the psychology of each situation. At no time in industrial history has it ever failed to be clearly apparent that an organization conducted with due regard for the upbuilding of the various key men in the organization is the true method of building a safe, stable, and permanent industrial structure. The prime consideration in the upbuilding of an aggressive and successful organization is a leadership which permits nothing but absolute fair play to every one in the organization, and which further permits nothing but absolute cooperation between the various departments of the business, firmly and effectively coordinated by a chief executive whose whole endeavor is to build up every responsible individual in every possible way, thereby automatically elevating the office of chief executive to a plane much higher than otherwise could be accomplished.

### Too Few Executives Study the Psychological Factors of Organization Procedures and Personnel Problems

Too few executives study the psychological factors which enter into their organization procedures and into the personnel problems which are ever present in both large and small organizations. Too few executives realize that every human being, no matter whether in a high position or a low one, takes an intense pride in his work, provided his scope of responsibility is so clearly defined that it can be regarded by each individual in a very personal way.

It is exactly this feature which is the basic consideration of bonus incentives, profit-sharing schemes, and all other such plans to bring out a greater personal interest on the part of each individual participating. A worker at a machine does not think half as much of the additional bonus which he makes in his pay envelope as he does of meeting and beating a fixed standard time. Not long ago the author was told that during the preliminary stages of the installation of a bonus plan, and before the workers, or even the foremen, knew what was coming, a gang boss in a foundry became so enthusiastic over meeting and beating the standard times set for the various tasks of his gang that he nearly got into trouble with his men on account of driving them so hard to make a record. Needless to say, when the bonus scheme was announced this enthusiasm not only kept up but it increased to a very remarkable degree, with the result that his particular gang achieved some very wonderful records of performance. The secret in the instance just recalled proved to be what is usually found in the majority of cases, namely, that the psychological effect of making a game out of every-day work has in itself a tremendous measure of merit, even without promise of extra financial reward.

Budgetary control is a mechanism which should be thoroughly understood before it is employed by any management. If an executive who has little use or consideration for psychological effects should think that the installation of a mechanism such as budgetary control will, in itself, produce any great results, he had better stop before he starts. It is in such cases as these where we should find a constant stream of complaint if, and when, the actual results differ to some extent from the budgeted expectations. In these cases, budgetary control becomes simply a guess, and a questionable allocation of actual results against the guess. Mountains of complaint will pile up to the effect that some one was a poor guesser, or else that the accounting department is incompetent because it does not properly allocate actual results against a more or less misguided set of guesses.

All executives who fail to appreciate that budgetary control has its greatest value in its psychological effects on the organization as a whole, are absolutely lacking in one of the greatest essentials of successful management. This not only applies to budgetary control but to any other mechanism for the assistance of management in the proper conduct of business.

### The Great Psychological Value of Budgetary Control

If we consider briefly some of the high spots in setting up a budget, we may obtain a clearer idea as to the great psychological value of budgetary control. In every industrial or commercial institution the forecasting of future operations depends primarily

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[1] Consulting Industrial Engineer, Stevenson, Harrison & Jordan. Mem. A.S.M.E.

Contributed by the Management Division and presented at the Annual Meeting, New York, December 5 to 8, 1927, of The American Society of Mechanical Engineers.

on general economic and market conditions. This means that the sales department—that department whose ear is on the ground at all times for future business—must make up its mind to two things: first, as to what it considers the possibilities of business will be for a certain period ahead, and second, as to what portion of the available business it feels it can secure. This is usually built up starting with the salesmen, who are far-flung in the field and who understand their own local conditions; then through branch offices where the various salesmen's figures are combined into the branch expectations; and from there to the main office where the expected business is assembled into one group by classes of product, and even units, if possible. This final assembly will become the quota section of the budget, and as these quotas have been carefully looked over and checked, it is quite reasonable to suppose that every individual in the sales department subscribing to these quotas is prepared to fight to the last ditch to produce the business which he has conservatively stated is possible of accomplishment. Does this not have a most powerful psychological effect on every member of the sales force?

These quotas then become the basis of the manufacturing operations. The raw-material requirements are arrived at by breaking down the various specifications of the product required. This gives the purchasing department its cue for the procurement of materials. The manufacturing department computes the force which it needs to produce this business after taking into consideration stocks on hand and delivery requirements. It can arrange its schedules to best advantage for the speed of operation indicated by the quotas submitted.

Should the manufacturing department, on account of its cost of production, feel that the quotas as furnished are not in line with best practices of manufacturing, it can submit to the management its thoughts in this direction, and the sales department can be approached as to what means can be taken to obtain a larger quota should the original one be too modest. The purchasing department likewise may call attention to the fact that the quantities specified cannot be purchased to best advantage, and the management must therefore decide with the purchasing department upon whatever relief may be thought best.

When all of these figures are assembled into a general budget, the controller's or budget department will be able to set up the general results and show a very complete picture of what would happen if the business operated on the basis of the quotas as originally set up by the sales department. A forecast profit and loss would be set up, and the treasurer's department, likewise, could see what funds would be required, how the accounts receivable would accrue, and what the financial state of the business would be at any time during the budgeted period.

The object of these brief references to the high spots of budgeting is simply to bring out the fact that every key man in the organization is *required* to visualize the future, to go through the moves of anticipated transactions before they have been begun, and to live through a specified period of future operations to such an extent that he will become thoroughly imbued with the necessity of making good on the figures which have been set up in the budget. The effect on the mind of each key man is tremendous. He assumes personal responsibility which otherwise could not possibly be assumed, and very few men today will shrink from assuming this responsibility when they are given the opportunity. If this does not involve psychology, then the author knows nothing that does.

When the budgeted period begins, the greatest psychological value of budgeting begins to become apparent. Watching the score of a World's Series game becomes child's play as compared to watching the score of actual results as they are set up against carefully budgeted expectations. In the case of the World's Series game, a cigar or a new hat may be at stake; in the case of the business game there are stakes of different kinds to be won or lost: first, the stake of accuracy of judgment of business and market conditions; second, the accuracy of judgment as to what the selling organization is capable of securing; and third, the accuracy of judgment as to how much it will cost to secure this business. It is a matter of pride to those charged with the duty of setting up the budget to make good and to beat the quota for quantity of business or the budget of expense as originally set up.

In the manufacturing, purchasing, treasurer's, and all other departments the same principles are involved. If the manufacturing department starts out on a schedule and is supposed to reach certain costs, it is the greatest game in the world to make good and beat the objectives which have been set up. If raw materials have been budgeted at a certain figure, the purchasing department will use every effort to beat these budgeted figures. If the treasurer's department think it will be necessary to borrow some money, they will strain every nerve to push forward their collections in order that the amount to be borrowed shall be less than that budgeted. In fact, throughout the entire organization the humdrum routine of every-day business becomes a live and interesting game, and a game of intense seriousness.

Now, go a step further and supplement a well-organized budgetary control by a scheme of bonus incentive whereby all individuals concerned can profit individually if the expected figures are equaled or beaten. The class of men occupying the higher positions, and even lower than the higher positions, will respond to the stimulus of budgetary control even if no incentives are provided. It seems to be a natural instinct in every American to want to play a game or to become interested in games which are played. No people in the world support to such an extent the various sports as do Americans. The number of persons who listened to the radio account of a certain boxing match a short time ago probably ran into the millions, and judging from the reports that some of the auditors dropped dead from excitement, there must be a tremendous influence exerted by our great American games.

Any management which allows the every-day transactions of business to drift into a humdrum and tiresome routine is guilty of mismanagement in the higher degree. Budgetary control is not a fancy mechanism to be indulged in by the business connoisseur or method fancier. It is a live and breathing mechanism which brings into play the vision, imagination, action, and whole-souled interest of every individual in an organization who is privileged to become involved in any way with its operation.

## Discussion[2]

H. L. Freeman.[3] An estimate is nothing more than a budget that gives in considerable detail the final figures that go into the general budget. This estimate is prepared by comparison with previous costs and with the information available at the time. The budget, of course, is intended to cover a year's work, and generally without revisions.

The design and construction of the separate jobs covered by the budget take place throughout the following year. An appropriation made from the budget estimate for a particular job based on preliminary information will not correspond to the latest requirements. That, of course, is one difficulty in forecasting some months ahead.

Another difficulty is that the executives, in looking over these

[2] The papers by Messrs. Jordan and Coes were presented together, and, the ensuing discussion applied to both papers. In the course of the discussion many questions were asked and answered at the time by the authors. These answers are incorporated in the closures, without being separately presented in the discussion.

[3] Cost Engineer, Dixie Construction Co., Alabama Power Bldg., Birmingham, Alabama. Mem. A.S.M.E.

budget items, generally have some self-satisfaction in cutting down the totals—presumably to save the company money. But when the actual costs are obtained, they more closely approximate the original estimates than the budget's revised figures.

The men who do the work in the field know these facts, and the psychological effect of the budget as being a goal is defeated. They feel from the start that it is impossible to meet the amounts appropriated, and so go along and do the best they can. In the case of a public-utility company, bonds can be issued for what the construction work costs, so it is a question whether or not the construction man has saved any money. This is one place where budgetary control does not necessarily produce reduced costs.

C. E. Wager.[4] The writer cannot agree with Mr. Freeman that it makes no difference whether or not the construction man estimates accurately, due to the opportunity of the public-utility company to finance capital requirements by the issue or bonds or other securities to the public. We must recognize that the cost of capital before long will be at a point where from a competitive standpoint we cannot afford to waste money in unusual and unwarranted expenditures. We must keep plant accounts down, and begin to trim interest charges as well as operating expenses.

Another thing that might be commented on is the statement to the effect that the central office apparently has a habit of reducing the estimates from the field. That is a very dangerous and unprofitable proceeding. It certainly will result in the conditions mentioned. In our own organization we always leave the estimate of the man who has the responsibility of turning out work stand as he submits it. He is responsible for the completion of the work as he estimates it.

In the matter of tolerance, particularly on construction expenditures, two different viewpoints may be taken. Assuming that we have a large project to be financed in advance, in arranging for the bond issue or other securities, as the case may be, it is well to permit the engineer to include an item for contingencies, so that the final actual cost will not exceed the estimated cost. We all know from experience that certain items will occur during the period of construction work which cannot be foreseen when the original budget is made. In laying out the financial plans in advance, contingencies must be provided for. In our own organization we weigh the original estimate, and if it is found expedient to include an item for contingencies, it is understood that no commitment will be made against the contingency item without definite authority in advance by the engineer and executives in charge of the operation. The percentage to be allowed on a fairly large project for contingencies depends entirely upon the engineer. One large plant had an item of 15 per cent for unforeseen contingencies. It is not specifically in the budget, but was fixed by the experience of the engineer. On all smaller jobs, contingency tolerances are left out of the estimate entirely, and variations plus and minus are permitted to stand without question. If the home office requires further explanation, it depends upon the nature of the requisition and the amount of the requisition. If a turbine is being repaired, for instance, the requisition might be overrun, and an explanation would be called for as to what had to be done.

C. H. Bigelow.[5] The question has been brought out a good many times that estimates for the budgets come from engineers primarily, and it is a fact that the engineers are not always able to get costs on which to base the estimates. In the writer's experience it has been a hard job to get costs for making an estimate. The hardest work of all is to get unit costs. Auditors should take that into consideration and give the engineers more with which to work.

[4] Discussion submitted bore no address.—Editor.

[5] Plant Engr., Spicer Manufacturing Corp., S. Plainfield, N. J. Mem. A.S.M.E.

Frank L. Sweetser.[6] Some one has asked if there is a difference between "budget" and "estimate," inferring that estimate refers to a particular job, while budget covers the business as a whole. This question of name is an interesting one. In the accounting field we have been trying to get some standardization. Estimates, and normals, and standards, and budgets are getting closer and closer to the same meaning all the time. The subject of budget control is a broad one, which cannot be limited by any name. An estimate in one case may mean a particular job, and in another case it may mean something entirely different. While data, statistics, and such things must be available, nevertheless the human element is the most important. Are you thinking about your problems, and are you having your organization think about them? Are they thinking about them in terms of the future? Looking into the past to get comparisons will avail but little. The leaders in industry are not comparing last year at all. They are comparing something else, namely, what is to be.

H. V. Coes. It is quite astonishing to note the speed and the acceleration with which budgeting is carried out once the organization is, sold, on the plan. And one of the reasons why budgetary control is not sold to the organization in so many cases is again a psychological matter. It is because the budget is so frequently handed down from the top, and the men are told to "do this and do that." Most men like to set their own goals in their own way. They like to attain those goals by their own methods provided they do not run counter to the general rules. The game of business cannot be properly played if some one proceeds one way and someone else a different way.

There are a number of fundamental rules and regulations which must be understood by all. The principal job is to make real budgetary regulation a game. It can be so made.

With reference to tolerances in budgeting, there is in the paper a chart of manufacturing expense. At the bottom of this chart is an item "Budget Correction for Variation in Productive Labor." In other words, we cannot in our business say in March, 1928, "The product from that plant and productive labor required to produce that product will be, for example, $54,000 for the month," because we are not making automobiles. Fifty per cent of the product is made to order for some one else. When we set up a budget, we set it up on what we term a normal period, which is the result of statistical studies covering a period of years. We correct the budget from the final figures which come in for the month as compared with the actual, and in the meantime our people all know that the management will permit, informally, a reasonable variation in the budget. No percentage figures are set for the variation, because in some cases a fixed percentage would be an amount of money that would be ridiculous. In other cases it might not be adequate to cover the situation, where one budget item might be badly out of line. We do not have set tolerances, but we do recognize the principle of tolerance. The factors that are taken into consideration are: the sales rate, the classes of merchandise or product, and the productive labor. The question has been raised as to reserves for extraordinary maintenance, as for machine breakdowns, which might occur only once in several years. We attempt to budget maintenance expenses and we have been fairly successful with it. But we have extraordinary expenses which cannot be predicted. Those charges are pulled out of the regular budget, and treated

[6] President, American Management Association, New York, N. Y.

as extraordinary expenses. If the item is to be prorated over a period of years, we carry only the prorated portion in the budget and the balance as a deferred charge.

J. P. Jordan. One of the purposes of the paper was to stress the psychological effect of budgeting in an organization. To be sure, we must have more or less mechanism to carry it out. We must know how to work a budget to a very considerable degree. In the last analysis, however, that is the least part of it; all the mechanism in the world will fail if it does not carry through to embrace the actual, whole-hearted interest of every one in the organization.

Look back over the successes in business, and the failures in business, and analyze the reason for successes and failures. If you can get at the facts in any case, you will find out that the success or the failure was in direct ratio to the attention paid by the management to psychology: that is, to the attention paid by the management in man-building, in impressing every one in the work with the enormous responsibility attached to each and every job, whether it is the president of the company, or the office boy delivering mail at regular intervals around the office.

Budgetary control came into existence not long ago. It is a comparatively new thing, as we term new things today, largely rating it from the standpoint of fact that it has only just about come into fairly general use. Budgetary control has been in existence for a great many years in the best-regulated companies, but today we see it quite generally used, or at least an attempt made to use it. Why is it? It comes right up to the point of psychological effect on the organization.

Doubtlessly many will say, "Well, yes, there are lots of businesses that lend themselves to budgetary control, but my business doesn't." There is no business that does not lend itself to budgetary control. Take into consideration that a budget, so-called, is really in two parts—the performance factor, the goal in volume of sales or quota, and the cost budget or the expense of doing it. They are two very different things. For instance, there is a sales department. So many sales representatives will cover so much territory. That is comparatively easy to set up. There are certain representative branch offices. There may be a definite budget for advertising. The men are kept on the payroll all the time, anyway.

It is not so easy usually to set up quotas with the sales department. The usual cry is, "We are not clairvoyants. We cannot read the future. We cannot say that we will sell." It is difficult to get the sales department to commit itself on what it is going to do, and on what it expects to undertake. That is all wrong. It is easy to budget expense, it is difficult to set up quotas of performance, and yet we must have them for a good many reasons. The psychological effect is the greatest reason for setting a goal. The sales department may say, "Well, we may hit way off, and become laughing stocks."

Nobody will do any laughing at all because of the fact that from past records, business conditions existing at the time, from the nature of the organization as a whole, from the excellence of the product, from the popularity, from its exclusive features or simply from the fact that the organization is manufacturing a stable product with a powerful selling organization behind it, it is possible to set up a quota. There is no reason at all for any one's hestitating to give an idea of what he is going to try to sell. The best of that is, that one and all, when he sets a goal, will do their utmost to meet or beat that figure. Whether it is met or beaten depends on many factors. It is in the analysis of those factors that we get the greatest value out of budgeting.

If we sit down with whoever is responsible for having set the goal, with various individuals, far-flung, perhaps, throughout the whole organization, and analyze the expense budget to ascertain why it was not reached, we are bound to develop the reasons. Therefore the next time the quotas are set up, the next time the budget is made, we have the benefit of all those things that happened, the reason for falling off here or for increasing there, and in consequence, the next quota will be far closer than the first one.

A certain company, on the basis of the budget, set up a profit and loss account on the telegraphic reports coming in up to midnight on the thirty-first day of the year, using standard costs and standard performance in connection with the budget. The directors met next morning, the first day of January, and dealt with big problems on which the profit and loss had an important bearing. When the actual figures came along about ten days later, they were less than one per cent off from the figures set up on the last day of the year.

Such accuracy cannot be reached right away, but like everything else, that point can be approached gradually, and perfection comes along that line very rapidly. It all depends on the managerial attribute or the managerial success in guiding the minds of the various people in the organization to visualize the future, to see the benefit of setting these goals, and the great advantage that is to be had through the whole organization—salesman, plant manager, foreman, and the worker at the machine. In plants we have known for many years where budgets or quotas are set up, 95 per cent of all the workers in the plant are just as crazy to beat a mark as the manager is to have them.

One of the questions that has been asked, inquired as to whether or not budgets should be made with a tolerance, say, $100,000, plus or minus, just as an engineer would specify a dimension in the design of a machine as 1 in. $\pm 0.001$. In making a budget, a tolerance is usually taken into consideration, except that it is, perhaps, on the plus side. When an expense budget is being made up, the tolerance should be for the fellow who has to make good on it, so that he has a chance to win his game. Otherwise he is being everlastingly cut down so that he never tastes the sweet fruit of beating the figures. Mr. Coes has said, and he is correct, that the budget handed down from up above is a pretty poor budget.

After the department head has made up his budget, the manager who is considerate will put the expense budget through with the tolerance a little bit on the plus side. He will say, "I want to make you safe on this and allow just a little more there so you have something to go and come on." The inconsiderate manager will not get far. He will screw things down so hard that everybody will be disgusted. He will not allow any tolerance, and that is just as bad as the other is good. There must be a tolerance in budgets. There is no such thing as exactitude.

Another question that was raised was that of the extent to which the engineering department entered in when budgeting overhead, indirect, controllable, and non-controllable charges. It all depends on the business. Some have engineers, others have none at all. Other businesses are all engineers. The extent to which engineering departments enter depends on the extent to which the business is engineering business. There are many business and mercantile houses that have budgets. The same thing applies to the haberdashery shop, or anywhere else where expenses are set up for the year for rent, fixed help, and all other expenses, and a quota is set up in advance in order to see what must be sold during the year to come out even.

The engineer cannot spend his time more profitably than by getting all the latest literature on budgetary control, standard costs, and those things that have to do with cash in the business, and learning what they mean. With all the engineering in the world, no business can run on a business basis until it has the proper costs to back up the engineering.

# Determination of Minimum-Cost Purchase Quantities

## The Development of a Formula That Considers the Principal Factors in the Cost of Purchases

By R. C. DA .S,[1] FLINT, MICH.

IN PLACING an order the purchasing agent must consider not only price but in addition quality, delivery, and quantity. Every experienced purchase executive knows that a cheap price may prove most expensive if the quality of the material makes it difficult to process or depreciates the ultimate quality of the product; if the material is not delivered promptly, causing expensive hold-ups of the production program; if the quantity purchased is so great that interest, storage, depreciation, and obsolescence charges unduly increase unit costs; if the quantity purchased is so small that the unit cost of procurement is disproportionate, or so large that interest and storage charges increase unit costs unduly.

In the better-managed plants, accurate information regarding prices and price trends is being obtained regularly from records of previous quotations, reporting services, trade journals, manufacturer's associations, governmental and semi-governmental sources, daily papers, graphical price analyses maintained by the purchase office, and many others. This information is studied carefully and constantly. The quality of purchased materials is being insured through the use of properly prepared specifications in making the purchase contract and in inspecting the goods when delivered. To insure deliveries as promised, vendor's records, showing capacity and past performance of each vendor from whom the company has had occasion to buy, are studied before the order is placed. These and other precautions may be taken to insure that the company gets the right quality, delivery, and price. However, the determination of how much to buy may not receive the same careful treatment.

It may be left to the judgment of some individual who is thought to be competent, very often the president of the company. It may be based on maximum ordering quantities determined from statistics of past consumption, having little reference to future needs. It may be based on immediate needs as indicated by present unfilled orders. Any or all of these methods may result in the purchase of quantities too large or too small to give a minimum total unit cost.

### Relation Between the Receipt and Consumption of Purchased Materials

The general relation between the receipt and consumption of purchased materials is indicated in Fig. 1. The ideal condition would be an assured delivery of the exact quantity of material necessary to meet the needs of the plant, at the exact time that the old stock is exhausted, making it unnecessary to carry reserve stocks. Of course, such an ideal is unattainable in actual practice, although some concerns have approximated it to a surprising degree. Obviously, the trend in inventory practice is to approach this ideal as a limit, as far as practicable.

In Fig. 1, values of time are represented on the axis of abscissas and values of quantities purchased or in stock on the axis of ordinates. The symbols in the diagram have the following meanings:

$Q$ = quantity purchased, which should be such that the total unit cost is a minimum.

$R$ = minimum ordering quantity.

$R_1$ = theoretical minimum. If there is no reserve stock, and a purchase order is placed when the stock on hand falls to quantity $R_1$, the old stock will be completely exhausted as the new stock arrives.

$R_2$ = reserve stock. It is assumed that some reserve will always be maintained to protect the plant against the failure of the vendor or the carrier to deliver as specified. The size of the reserve depends on the time required for procurement and the nature of the article rather than on the size of the order.

$S$ = rate of consumption, expressed in pieces per year.

$T_1$ = procurement time, expressed in years. It includes the time from the origination of the purchase requisition to the delivery of the goods to stores. The procurement time will vary with kinds and classes of goods. However, for any given item

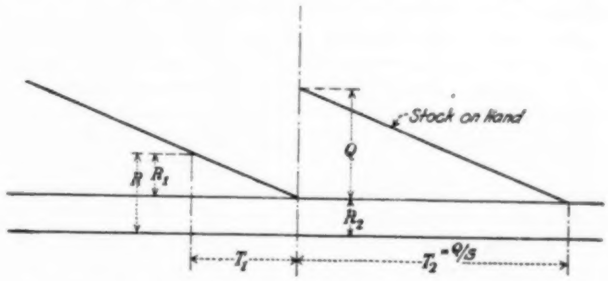


Fig. 1 Relation Between Receipt and Consumption of Purchased Goods

it does not vary greatly with the size of the order. It can be considered to be a constant.

$T_2$ = the time during which the stock is being consumed, expressed in years.

### The Minimum Ordering Quantity

In many plants, one source of authority for the placing of a purchase order is the purchase requisition originated by the balance-of-stores department. When the available stock of a given item, as shown on the stores ledger, falls to some predetermined quantity, a purchase requisition is originated and sent to the purchasing department. If it is not the practice to apportion material against planned orders, the quantity will refer to the stock on hand. This predetermined quantity is usually referred to as the minimum ordering point or quantity. Obviously, its value depends on the time required for procurement and the rate at which the item is being consumed. This being so, $R_1 = T_1S$.

The actual reserve will include the theoretical minimum plus the reserve necessary to protect the plant against exhaustion of stock before the arrival of the new stock. In general, the greater the time of procurement or the quantity consumed, the greater the reserve that must be carried. The probability of delivery failures or rejections due to failure to meet specifications tends to increase as these factors increase. The actual reserve can be

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[1] General Motors Institute of Technology.

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expressed as a function of the theoretical minimum. Let $F$ = ratio of actual to the theoretical minimum ordering quantity. Then

$$\begin{aligned} R &= \text{actual minimum} \\ &= FR_1 = FT_1S = R_1 + R_2 \\ R_2 &= R - R_1 = FT_1S - T_1S = T_1S(F - 1) \end{aligned}$$

In the above equations $T_1$ is considered to be a constant.

### The Maximum Ordering Quantity

The quantity ordered also may be controlled by means of the balance-of-stores ledgers. In many cases a quantity, usually called the maximum ordering quantity, appears on the ledger sheet for each item carried in stock. This is a predetermined quantity intended to limit or specify the quantity which shall be ordered at any one time. If too little is ordered at any one time, the unit cost of procurement will be too great. The cost of procurement includes such items as the expense of originating the purchase requisition, the time of major executives spent in consummating the purchase, the time of buyers and clerks spent in investigating markets, securing bids, and placing purchase orders, time spent in following up the order, the expense of receiving and inspecting the goods, the expense of stowing, the expense of closing out purchase orders in the purchasing and accounting departments, and similar items. The determination of this value for a given item means considerable analysis. However, when once determined it stands as a standard cost until there is a considerable change in conditions.

As the quantity purchased at any one time increases, the unit cost of procurement decreases, but the unit interest and storage charges increase. The total unit cost of the item decreases up to the point where increasing unit interest and storage charges outweigh decreasing unit procurement charges. Beyond this point the total unit cost increases. Obviously, the maximum ordering quantity should be such that it will hold the total unit cost at this turning point.

The interest charge depends on the quantity purchased, the time of consumption, and the rate of interest. It may be determined as follows:

Let

$$\begin{aligned} W' &= \text{quantity on which interest is charged} \\ &= Q/2 + R_2 \\ &= Q/2 + T_1S(F - 1) \\ T_2 &= \text{time of consumption} = Q/S \\ I' &= \text{total interest charge} \\ I &= \text{current rate of interest, and} \\ C'' &= \text{unit purchase price.} \end{aligned}$$

Then

$$\begin{aligned} I' &= W' \times C'' \times I \times T_2 \\ &= [(Q/2) + T_1S(F - 1)]\,\frac{C''IQ}{S} \\ &= Q^2\,\frac{C''I}{2S} + QT_1(F - 1)C''I \end{aligned}$$

The storage charge depends on the unit storage space required, the cost of storage space, and the time of consumption. It may be determined as follows: Let

$P$ = unit storage charge. This includes the proportionate share of the general overhead charges as well as those which result from the operation of the stores department.

$B$ = bulk factor, expressed in square feet of net storage space required per unit of item. Storage space is valuable. Against it can be resolved many charges such as light, heat, taxes, ininsurance, wages, and salaries. The greater the quantity purchased, the greater the charge, offsetting somewhat any savings from quantity buying. The term "net floor space" means net usable floor space, exclusive of aisles, steel bin frames, etc.

$E$ = storage charge, expressed in dollars per square foot of net storage space per year. It is based on the expense of such items as were mentioned in connection with $B$.

Then

$$\begin{aligned} W &= \text{total quantity in stock on receipt of the purchase} \\ &= Q + R_2 \\ &= Q + T_1S(F - 1), \\ P &= BET_2 \\ &= BEQ/S, \text{ and} \\ PW &= \text{total storage charge} \\ &= BEQ/S[Q + T_1S(F - 1)] \end{aligned}$$

The minimum-cost quantity can be found by setting up an equation of total unit cost, differentiating with regard to quantity, and placing the first derivative equal to zero.

If $G$ represents the total procurement cost, the equation of total cost may be written

$$\begin{aligned} C &= \text{total cost of the order} \\ &= G + I + PW + C''Q \\ &= G + Q^2\,\frac{C''I}{2S} + QT_1(F - 1)C''I + Q^2\,\frac{BE}{S} + QT_1(F-1)BE + C''Q \\ &= G + Q^2\left[\frac{C''I}{2S} + \frac{BE}{S}\right] + QT_1(F-1)(C''I + BE) + C''Q \end{aligned}$$

To simplify the statement, let

$$\begin{aligned} K &= \text{interest factor} = \frac{C''I}{2S} \\ H &= \text{storage factor} = \frac{BE}{S}, \text{ and} \\ N &= \text{reserve-stock factor} = T_1(F-1)(C''I + BE) \end{aligned}$$

The total-cost equation can now be written as follows:

$$C = G + Q^2(K + H) + QN + C''Q$$

Dividing through by $Q$, it may be converted into an equation of total unit cost, as follows:

$$C' = \text{total unit cost} = G/Q + Q(K + H) + N + C''$$

Differentiating with regard to $Q$, we have

$$\frac{dC'}{dQ} = K + H - G/Q^2$$

Placing the first derivative equal to zero,

$$K + H = G/Q^2$$

$$Q^2 = \frac{G}{K + H}$$

$$Q = \pm\sqrt{\frac{G}{K + H}}$$

In as much as the negative sign has no practical significance, the equation for determining the minimum cost purchase quantity is

$$Q = \sqrt{\frac{G}{K + H}}$$

In using the equation, the values for $B$, $E$, and $G$ would be determined by investigation. But once determined, they would be standard values until there were some considerable changes in conditions affecting them. The value of $S$ would be derived either directly or indirectly from the production program. The value of $C''$ would be obtained from the accepted bid.

The equation is not intended to take the place of executive

judgment but rather to supplement it. The executive's decision may be affected by considerations of quality, delivery, price trends, obsolescence, and depreciation, as well as quantity and quoted prices. The following example will suggest possible applications of the equation.

*Example.* It has been determined from the production program that approximately 10,000 pieces of the material in question will be required during the coming six-months' period. The market price is $0.10 per piece. The outlook is for a stable market. The procurement time is approximately four weeks. The expense of procurement for this class of material is estimated at $10.00 per order. The material is stored in standard bins, 2 ft. square, having a cubical content of 8 cu. ft. There are four tiers in a bin stack. Approximately 100 pieces can be stowed in a bin. Normally a 5 per cent reserve stock is carried for this item. The cost of net storage space is estimated at $4.00 per square foot per year. The current rate of interest is 6 per cent.

$$B = \frac{4}{100 \times 4} = 0.01$$

$$S = 20{,}000 \text{ pieces per year}$$

$$H = BE/S = (0.01 \times 4.00)/20{,}000 = 0.000002$$

$$K = C'I/2S = (0.10 \times 0.06)/(2 \times 20{,}000) = 0.00000015$$

$$G = \$10.00$$

$$Q = \sqrt{\frac{G}{K + H}} = \sqrt{\frac{10.00}{0.00000015 + 0.000002}} = 2145 \text{ pieces.}$$

The minimum ordering point would be determined as follows,

$$F = 1.05$$

$$T_1 = 4 \text{ weeks or } 0.0833 \text{ year, approximately}$$

$$R = FT_1S = 1.05 \times 0.0833 \times 20{,}000 = 1749 \text{ pieces.}$$

In this case, it would be advisable to purchase on the market in lots of 2200 pieces. The balance-of-stores department would originate a purchase requisition when the available supply fell to 1750 pieces. Under this arrangement, each lot would cover approximately $5^1/_2$ weeks' requirements. Before placing an order for a particular lot, actual consumption could be checked against the original consumption estimates, based on the production program.

## Discussion

Alonzo Flack.[2] This paper is undoubtedly the result of considerable thought and care in its preparation. After studying it, no fault can be found with its mathematical accuracy. It would seem that the practical application of the formula to all kinds of purchasing is the question to be discussed.

Many classes of materials are purchased in any large or small plant:

*a* Some quite regularly in easily predetermined quantities;
*b* Some in easily predetermined quantities but at irregular or uncertain intervals;
*c* Some in large quantities, but only once every year or two;
*d* Some only on schedule, a stock never being carried; and
*e* Some, such as tools, equipment, and supplies, in varying quantities and times of delivery.

The author's formula will apply best to the condition first mentioned. A large automobile company that schedules its production six months ahead is a good example. Even such a company revises its schedules monthly, after checking its schedules of production with its sales. When a more complicated situation arises such as is indicated in the other conditions, trouble may be found in applying the formula.

A tremendous number of variables are encountered in purchasing that tax the ability of a purchasing agent. Seasonal demands, changes in style, changes in prices, changes in manufacturing and marketing methods, will affect the practical application of the formula.

There are thousands of purchasing agents, their assistants, and storekeepers. The abilities vary widely. Many are of limited education and training. Some are of great ability but have forgotten their mathematical teachings. Such would find an easier way to determine the quantities to purchase, even though not as accurate.

Frequently the character of the purchasing agent has a great influence on the determination of minimum-cost purchase quantities. It is his knowledge, his accurately kept records and statistics, and his influence over those whom he supervises and from whom he buys that stamp him a success. Mechanical and mathematical aids are but auxiliary to his ability.

It is therefore a question whether the average person handling stores and purchasing can intelligently apply the formula, and to what extent it might be used. To get an unbiased practical reaction to the paper, a very successful purchasing agent, one whom for eighteen years has purchased large quantities of materials, has secured unusually favorable prices, and has been known for having prompt deliveries, was approached. He expressed himself as follows:

> The paper is the result of very careful thought of a very scientific mind and is a finished piece of work theoretically. It may be applicable to a very large concern with widely scattered operations, but is very impractical to a company doing three million dollars' worth of business per year, whose purchasing department has been working under the same supervision successfully, including the war period, when 1200 people were given uninterrupted employment. Not one single employee lost five minutes' time for the want of material with which to work, neither was substitution of material necessary for this operation. Based on this paper the cost of purchases (at $10 per order) would be $7200, whereas the actual cost was $900 with a very much simpler method than that above, which has proved 100 per cent efficient for 18 years.

In the writer's 20 years of service to industry, he has not found it practical to reduce the determination of minimum-cost purchase quantities to a mathematical formula.

Robert T. Kent.[3] The criticism of the practical purchasing agent quoted by Mr. Flack illustrates a point of view that probably has done more to obstruct the advancement of good management methods than anything else. Mr. Henry L. Gantt, one of the keenest minds that this Society ever had, coined an epigram which fits very closely individuals of the type of this "practical" purchasing agent. The epigram is: "The way we have always done it is probably wrong."

There is nothing so obstructive to progress as satisfaction with the way we have always done it, and the man who says that he has been successful for 20 years and is satisfied, is a man who has closed his mind against any progress and any advancement. Where would industry be today if every one connected with it took that view? Progress is made because we are not satisfied, and we know that our present methods are not the last word. If anybody can show better methods we should be only too willing to adopt them and discard our present methods.

[2] The Emerson Engineers, New York, N. Y.

[3] General Manager, Bridgeport Brass Co., Bridgeport, Conn. Mem. A.S.M.E.

W. R. Clark.[4] Mr. Raymond has given us a paper covering a formula for manufacturing,[5] and the author has given us a formula for purchasing. There is a missing link between these papers somewhere. Both are based upon certain assumptions and have neglected other considerations which must be entered into to make them wholly applicable.

Mr. Raymond's paper has neglected the question of labor fluidity, which involves the cost of training and the payment for overtime where those factors enter into the economic lot sizes, based upon demands of the purchasing agent. In other words, you may have a certain economic lot size which it is desirable to put into manufacture, provided you have the manufacturing facilities to get out this lot size and meet the purchasing agent's demand for delivery. If these facilities are not available, the problem becomes one of carrying more labor, training it, organizing a night shift, or paying overtime on the day shift.

Another factor that complicates the problem is the investment in surplus machinery, power, floor space, etc. in order to minimize the fluctuations in labor supply. Extra machinery may be installed in the plant, and extra labor can be temporarily put on this extra machinery in order to meet purchasing demands and permit economic-lot-size manufacture, but the cost of carrying this equipment is considerable. These are factors which should be covered somewhere in the equation. Another factor that enters into the problem is the variations of raw-material costs. At certain times, when raw-material prices are low, it may be advantageous to operate and put into stock an excess of goods over the economic lot size.

Referring to the author's paper, the condition of the vendor's factory may affect delivery. This condition varies from day to day, from week to week. Considerations must be given to the condition of markets, which affect the vendor's supply of raw material, and also the seasonal price variations of the raw material for the vendor.

Probably these variables can be tied together somewhat by a type of contract which is being made to a limited extent, that is, a procurement contract rather than a series of orders. It may call for a delivery somewhere between a maximum and minimum amount during a given period. Such a contract is somewhat flexible from the vendor's standpoint, where he can, to a certain extent, manufacture to his economic-lot formula and can put into his stores, temporarily, material in excess of specifications in order to enable him to meet the demands of his customers. The customer, in turn, may be able to work to a formula requiring less material in his storeroom.

The whole problem merits the getting together more closely of the purchasing agent and the source of supply from which he procures his material, in order that they may work out this problem as a whole instead of using two formulas not entirely connected.

The Author. The method of determining minimum-cost purchase quantities is not intended to be a substitute for the purchasing agent's experience and ability, but rather a supplement to it. Mr. Flack is correct in stating that such "mechanical and mathematical aids are but auxiliary to his (the purchasing agent's) ability." However, this does not preclude the possibility that such methods may render valuable assistance to the purchasing agent.

The method described in the paper is intended to aid in establishing maximum and minimum ordering quantities accurately. Obviously, it is of value only in connection with the solution of these problems for classified materials. It can be used for such materials purchased at regular or irregular periods of considerable duration or on schedule, as well as for those purchased in large quantities at relatively short regular intervals. However, the reliability of the formula is less in the former cases. Therefore more depends on the ability and experience of the purchasing agent. Nevertheless it is hardly probable that such ability and experience exercised by rule of thumb will be as effective as they will if they are supplemented by a scientific analysis of the problem, such as the proposed method will give.

Seasonal demands, changes in style, etc. would be considered in making the production program. Therefore they would be considered by the formula. In most cases the revision of the original program, as conditions develop through the year, would not affect the maximum and minimum ordering quantities seriously, unless the revisions were quite considerable. The properties of the curve of total unit purchase costs are such that there can be a considerable deviation from the minimum-cost quantity before total unit purchase costs increase seriously. The necessity for revising would vary with each item. In the case of the more important items which are used regularly in large quantities and whose purchases involve large sums of money, it might be advisable to revise the maximum and minimum ordering quantities whenever there is a general revision of the production program. The great majority of items would only be revised periodically.

The method is not intended for use with speculative purchasing. Impending increases or decreases in the price level of a given item are always a matter for the judgment of the purchasing agent, supported by such information as may be collected by his own or the company's statistical organization. It is always his privilege and responsibility to recommend such deviations from the maximum ordering quantity as he may consider advisable. However, it is doubtful whether he should be permitted to make such deviations at his own discretion, except in the case of those items whose purchase is frankly speculative.

There is undoubtedly the same wide variation in the abilities of purchasing agents that there is within any other executive class. Such variation is an argument for a more exact and careful selection and training of executive material rather than an argument against the use of more exact management methods. However, the work of determining maximum and minimum ordering quantities, in general, would not be done by the purchasing department. The actual solution of the problem for any given item is a routine matter, once the proper information has been supplied.

As previously stated, the formula is not intended to give exact solutions on which blind reliance can be placed. A number of factors in the purchase problem have purposely been left out because they are too intangible and their inclusion would unnecessarily complicate its solution. The formula is intended to assist the purchasing agent in making a more exact analysis of a given purchase problem in so far as the factors considered by the formula are concerned.

[4] General Works Manager, Bridgeport Brass Company, Bridgeport, Conn. Mem. A.S.M.E.

[5] This discussion also applies to the paper, "Economic Production Quantities," by Fairfield E. Raymond, MAN-50-10.

# Control of Quality

## Conditions and Circumstances Affecting Control of Quality Obtaining in the Shops of a Large Manufacturer of Optical Instruments and Accessories

By WALTER W. GRAEPER,[1] ROCHESTER, N. Y.

THE problem of the control of quality and its relation to production, in its general aspect, is the same in all manufacturing plants. The psychology of inspection, its necessity and value in securing a uniformity of product, is universally understood and recognized. It is doubtful if there may be found anywhere a factory in which some form of inspection is not applied. There may be instances in which it is carried out more or less unconsciously or in such a manner that it is not recognized as a separate function.

### Growth of Need for Inspection

The need for inspection has grown and developed with the change and growth of modern industry. When production and distribution of goods was operated on an individualistic basis, when the artisan worked as an individual, either at his home or in his shop, alone or with the aid of a helper or apprentice, inspection, as we know it today, had no place in the scheme. Yet standards of quality, as far as the finished product was concerned, were scrupulously maintained. This product was in most instances due entirely to the labor and skill of the individual working with his own tools. But with the development of the simple tool into a variety of complex pieces of power-driven machinery, specialized for the mass production of parts of commodities, the little workshop grew into an enormous factory in which hundreds and thousands of men and women were gathered together, organized into an elaborate system of labor, each working into the hands of the other, all of them collectively producing one article which frequently passed through numerous other operations and processes before it was turned into a commodity ready for distribution and use. Under these conditions, with the individual almost completely submerged, with the pressure arising from competition and the necessity for producing articles of high quality but at low cost, inspection, following processes and operations, of component parts, and, finally, of the finished product has become to a greater and greater extent a balance wheel which prevents these huge organizations from driving to ruin. The effect of a lapse of quality from established standards on sales volume, prestige, and good will is too well known to merit discussion.

### Value of Proper Inspection Generally Recognized

The value of proper inspection is universally recognized, but the methods of its application vary greatly. Probably the highest development of inspection methods is to be found in those plants devoted to the manufacture, in large quantity, in a more or less constant stream, of some highly standardized product such as the automobile. Beginning with the raw material, running through a bewildering number of operations, and ending with the completely assembled and finished machine, every step has been safeguarded by means of inspection. This is necessary because the ability of the machine to function, its utility, its length of life, and, in fact, under modern methods, its very existence depend on how closely to established standards its parts have been fashioned. Present production methods are such that a close check must be kept on the work in progress. Division of labor has resulted in economies which cannot be abandoned but it has also reduced the individual to an automaton so that, to a great extent, his incentive toward a striving for quality and his pride in his work have been lost. Barriers in the form of inspection must be erected to keep the quality of the results of his labor up to a standard which may be found acceptable.

Before going into a discussion of the problem of the control of quality as it presents itself at the plant of the Bausch and Lomb Optical Company, it may be well to refer briefly to the conditions and circumstances which obtain.

### Conditions and Circumstances Obtaining in Optical-Instrument Manufacture

This company is engaged in the manufacture of optical instruments of almost every description, together with an allied line of accessories not all of which may be classed as optical; of a large variety of articles made of glass, such as mirrors, reflectors, lenses, and prisms; of ophthalmic lenses and spectacle frames and mounts; of lens-grinding and polishing machinery. It is difficult to convey an idea of the complexity of these products by merely enumerating them. Optical instruments alone embrace so varied an assortment that it is possible only to those in the industry to become familiar with even a small percentage of them. The manufacturing problems which confront this organization are complicated by the fact that, gaged by the production of standardized articles manufactured in many other factories, the quantities involved are small. In the optical-instrument line alone there are roughly three thousand sales units according to the latest count. In the case of the most popular model of microscope the yearly production does not greatly exceed five thousand. For a great many units five hundred is considered big production, while others are made in lots of twelve to one hundred. In ophthalmic lenses and spectacle mounts and frames the quantities involved run into huge numbers, but the almost infinite variety of possible combinations of lens curves, types and shapes, colors and shades, and, in the case of frames and mounts the same conditions with respect to styles, materials, and the variables in the matter of dimensions required to fit them to heterogeneous human heads, complicate the problem to such an extent that the value which lies in great quantities in production is practically nullified. It has been found desirable to make use of practically all standard types of inspection methods, and means are frequently employed which are peculiar to the optical industry.

Without going into detail, it may be pointed out that facilities are available for making laboratory tests of raw materials which are used. Sands and chemicals for making optical glass must be tested in order that the glass produced may have definite characteristics as to index of refraction, dispersion, color or freedom from color, transmission, and absorption. Failure to control these characteristics leads to failure in the performance of complicated optical systems such as microscope, telescope, and photographic objectives. Metals of various kinds, from the gold which is used for spectacle frames and mounts to the brasses and steels from which instruments and tools are made, are tested to insure against failure during manufacture and use.

Tool inspection follows the procedure commonly adopted for

[1] Bausch & Lomb Optical Company.

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checking the accuracy and fitness of tools which are used in manufacturing processes. This work is carried out by a department set up for that purpose.

### Checks, Tests, and Inspections

Checks, tests, and inspections all through the processes of manufacture are required to maintain quality at the desired level. The diversity of the product brings into use a great variety of devices, instruments, and tools. These range from the usual gages and measuring devices for comparing physical dimensions, to refractometers, photometers, and many specialized optical instruments for measuring optical constants, curves, and angles of prisms and lenses.

Instruments especially designed and built in the plant for definite test or adjustment purposes are utilized. As a rule these are of such a nature that they are adapted only for the particular purpose for which they were designed, but not infrequently they develop into devices which, by reason of their accuracy or ease and rapidity of use, are adaptable for similar types of work in other industries. The contour-measuring projector is a good example of instruments of this kind.

Such instruments may be unusual, but the manner and reason for their use conform with standard practice for test and inspection. No doubt other industries find the development of specialized tools and instruments equally invaluable.

Previous to final inspection of the finished product, the control of quality is in the hands of inspectors who are responsible to division superintendents and department foremen in charge of production. This arrangement is based on the theory that the responsibility for the quality of the finished product should be shouldered by those who make it.

However, a check on the manufacturing departments has been provided. The final or finished-instrument inspection department is charged with this duty. It functions as an independent organization, responsible to the management, which passes judgment on the product of the factory. It is expected to carry out the policy of the management, and with this policy as a basis it establishes standards of quality and is empowered to force adherence to them. It has no direct authority or jurisdiction over the various processes of manufacture, yet its influence extends back to them. The manner in which this influence makes itself felt will be discussed later.

Due to the nature of the product, sales in the instrument lines are frequently made directly to the ultimate user. For this reason it is found to be advisable to fill many orders in the assembly departments. Such orders accompanied by the goods are routed through the inspection department for final approval and test. Other articles of a standardized nature are held in designated stock rooms after passing through the inspection department. From these points they are sent to the shipping department as orders are received. Since the inspection department is held responsible for the condition of the product as it leaves the factory, it has the authority to determine what articles may be handled in this manner and to restrict the length of time they may be held in stock without reinspection.

### Work of Inspection Department Not Entirely Non-Productive

The work of the inspection department is not entirely nonproductive. There are, for instance, instruments which are finally adjusted as they are being inspected and tested. On certain types of instruments some assembly work is done. This is confined to those which would have to be taken apart for the purpose of inspection if they were received in a fully assembled condition. The guiding policy in this connection is to do such assembly operations which do not add materially to the inspection time, but which result in a saving of a certain amount of time for the assembly departments.

The routing of equipments and combinations of equipments as ordered by the customer through the inspection department is advisable in order that they may be set up and put through a practical test in much the same manner in which they will be set up and used later by the purchaser. Because of the variety of units which are offered for sale, from which the purchaser may choose for his own requirements, it is not practicable to attempt to carry such equipments or combinations of units in stock for immediate delivery. This is also true of orders calling for special instruments and parts or modifications of instruments regularly supplied.

As has been stated, the tests are of a practical nature. Therefore inspectors who have been trained in the use of a large variety of instruments are required for that purpose. In general, instruments of a given kind or type are assigned to the various inspection groups. As a result, inspectors become specialists in these lines. For example, photographic and projection lenses are handled by one group, projection and photomicrographic apparatus by another. A third is responsible for a variety of units which are produced in relatively small volume. Among these may be mentioned microtomes and accessories, field glasses and telescopes, botanical apparatus, blood-cell counting apparatus, centrifuges, colorimeters, magnifiers, and microscope accessories. Optical measuring instruments, microscopes, and ophthalmic instruments are inspected and tested by individual inspectors. There is considerable overlapping among these groups and individuals, and to some extent it has been found possible to train certain inspectors along more than one line to take care of fluctuations in the volume of business and to provide for emergencies in the way of absences. It may be of interest to interpolate here that the labor turnover is practically negligible.

### Spot Inspection as Check on 100 Per Cent Inspection

In attempting to control the quality of such articles as ophthalmic lenses, lens frames, and mountings, and spectacle cases, the method of random or spot inspection is resorted to as a check on the 100 per cent inspection which is made in the various manufacturing departments. The purpose is to obtain the facts relating to the quality of the product for the management and at the same time to bring them to the attention of the manufacturing departments for their guidance. Since the 100 per cent inspection is carried on by operators paid on a piece-work basis, a check on their work is imperative. Here again the inspection department has no direct authority over manufacturing processes. It may recommend, and the psychology on which the relationship between the manufacturing departments and the final inspection departments is based is such that, as a rule, its recommendations are carried out. The effectiveness of any recommendations is considerably enhanced if the inspection department has built up for itself a reputation for fairness and impartiality, if it states its case firmly, but at the same time moderately, preferring rather to understate than to exaggerate.

Optical instruments which are manufactured for the Army and Navy are subject to the approval of Government inspectors. A naval officer is stationed at the plant in the capacity of inspector. Close cooperation is therefore required in order to meet the exacting requirements of Government specifications. The final inspection department does not concern itself regularly with this product.

### Problem of Establishing Standards a Complicated One

With this rough outline of the conditions and circumstances which exist in mind, it will be admitted that the problem of

establishing standards—for it is the function of this department to establish standards—and maintaining them is a complicated one. The policy of the company must be interpreted in such a manner that it may be applied practically to working standards for the various things which are made. Specifications which have been worked out by the technical and engineering departments in the form of blueprints and drawings are available in the majority of cases. Otherwise samples are used, so that, as far as physical dimensions, materials, and finish are concerned, there is usually something definite by which inspection may be guided. In the matter of performance there is constantly need of taking recourse to more intangible standards, standards for whose interpretation judgment must be relied upon. In all optical instruments and appliances image quality, to take a concrete example, plays an important role. To a certain extent only can this be controlled by means of samples. In the final analysis this extremely important matter must be controlled through the judgment of an individual who has acquired through experience the ability to state when an image is of sufficiently good quality to pass the test for a particular instrument. There are optical instruments, especially measuring instruments, for which it is possible to lay down very definite specifications in the matter of performance. A refractometer, for instance, may be held within certain limits of accuracy which may be determined by measuring on it certain test objects whose indices of refraction have been measured by means more accurate than the instrument in question. Whenever judgment plays as an important a part as it does in connection with inspection of optical instruments, every precaution must be taken to make sure that such judgment is based on a practical, sane, and reasonable foundation.

Variations from fixed theoretical standards occur in manufacture even when the utmost precision is required and no matter how definite the standards which have been established or how closely the limits have been prescribed. When judgment enters, the degree of variation becomes all the greater. For this reason, when standards of quality have been established in terms of samples, it is of utmost importance that these standards be studied and reviewed from time to time in order that judgment may be restrained from wandering too far from the desired limits. It is probably generally recognized that the normal tendency of an inspector is to become more critical without intending to do so and believing with an honest conviction that no change in the quality of his judgment has taken place. This tendency should be taken into account in handling the inspection problem.

### Contending Forces Which Influence Inspectors

There are two contending forces which influence the inspector. The one comes from the outside in the form of complaints by consumers and from the sales organization, which normally is a booster for higher quality in order that it may meet and overcome sales resistance arising from this factor. The other comes from inside the factory walls and arises from the struggle to keep down costs. It is particularly strong when manufacturing difficulties arise, when rejections mean retarded delivery, scrapped parts, and heavy losses. The quality of the same or similar product made by the competition becomes a component of one or the other of these forces. The direction in which it is effective depends upon whether this quality is higher or lower than that of the product with which it is being compared. It is not possible to maintain so fine a balance as an equilibrium between these forces under any circumstances, and frequently compromise must be resorted to. The effect is similar to that of a pendulum which vibrates between two points, and it is the function of the inspection department to make sure that the amplitude of vibration is restricted to a minimum—that the pendulum does not swing too far in either direction.

Customers' complaints in a large measure determine the limit on the one hand. Even here judgment must be used, for there are always to be found individuals and dealers who are extremely free to express themselves, but who lack authority. There are those whose demands are such that near perfection is required to satisfy them. To base standards of quality on their desires would be ruinous and impracticable from a commercial standpoint. Manufacturing difficulties and sales resistance due to high costs are the chief determining factors which must be recognized to prevent the swing of the pendulum in the opposite direction. As it is the policy of the management to head the procession, careful watch must be kept on the quality of the goods manufactured by competitors.

One of the most potent devices for transmitting back to the manufacturing and assembly departments the more or less intangible standards of quality are the inspection reports. Such reports serve two purposes. They convey the decision of the inspector together with his reasons in definite form and, when they have been analyzed, they form a record which is of practical use when reordering a lot of the same article. Since it is a part of the routine that manufacturing authorizations must be approved by the various executives whose departments are involved, the opportunity is automatically presented to the inspection department to make criticism or to suggest changes in design or method of manufacture which experience with the preceding lot of instruments warrants.

Conferences at which are present representatives of the engineering, production, manufacturing, and inspection departments before starting work on an article, have genuine value in creating a proper understanding of the problem at hand and in preventing thereby future difficulties. They are equally effective in getting results when trouble has been encountered at some stage of manufacture.

### Inspection-Department Policies

It is the policy of the inspection department not only to pass or reject the articles which come to them, but to find, when possible, the reason for failure and the source of the trouble. This policy frequently results in real saving, especially of time, for, as a rule, the inspector is in a more favorable position to detect sources of trouble in connection with performance than the individual who makes the parts or assembles the instrument. It results, further, in a closer contact with the manufacturing departments and presents an opportunity for a type of cooperation conducive to a better understanding between workman and inspector. No one relishes the idea of having his work rejected, especially when earnings are affected, but when the reasons for such rejections are pointed out together with information which is helpful in preventing similar mistakes in the future, it has been found that the natural tendency toward resentment has been mitigated, and that the average individual will make an honest effort to improve the quality of his work. Valuable suggestions relating to design and methods of manufacture frequently result from investigations of the causes of trouble.

It is the policy of the inspection department to give information whenever possible, for no matter how carefully drawings have been made, or how completely limits have been assigned, there constantly arise questions which must be answered, and information which cannot be placed on blueprints must be gathered if the complete intentions of the design are to be carried out in the finished product.

The idea that rigid inspection and high cost go hand in hand still persists in many places. The very opposite should be true provided that the inspection is intelligently conducted with a complete knowledge of the conditions which affect the design, manufacture, and use of the commodity which is manufactured.

Inspection if properly conducted should result in economy. Troubles may be quickly detected and their sources eliminated if the facts uncovered by the inspection department are utilized by the manufacturing departments as well as by those responsible for design. The solution of the problem of maintaining standards of quality is hastened if inspection is looked upon as a real source of helpful information and a means toward progress, instead of being considered merely as a retarding factor in production.

The philosophy of inspection is comparatively simple. The fundamental principles involved are such that they may be considered almost axiomatic. Yet, contradictory as it may seem, successful control of quality by means of inspection is difficult of attainment because of the complexity of the problem. Nevertheless, when production is approached by the management with as much emphasis being placed on quality as on quantity, when the factory personnel appreciates the value to itself of inspection and its by-products and is willing to cooperate to the fullest extent, when the inspection department has the proper conception of its responsibility and receives the necessary support to maintain its morale, adequate control of quality is possible of attainment.

## Discussion

L. G. Cattermole.[2] The author shows that the Bausch & Lomb Optical Company has followed the procedure of many other large progressive organizations in having developed sound, practical inspection methods. In general it would seem that there has been a letting down in quality standards among manufacturers of the low- and medium-priced products. This perhaps, has been due to increasing demand by the management for increased sales and decreased costs, influenced by the present narrower margins of profit in industry. While increased competition has a tendency to lower prices, it often has a tendency also to lower quality. In other words, the proper control of quality is not always coordinated with production.

Fundamentally, division of labor necessitates inspection to maintain predetermined standards of quality which would otherwise be unknown or not fully understood by the workers. When properly applied, it places responsibility for defective workmanship or material where it properly belongs. Carried to its logical conclusion, it insists on the immediate rectification of conditions where the percentage of rejections or repairs is too high. Workers, as a rule, endeavor to keep their work up to the requisite standards, when these are known, fully understood, and when they can be practically attained.

The middle road must be chosen between standards which are too low (or no standards at all) and standards which are almost impossible of attainment. In general, the small company errs in the first instance, and the large organization in the second. Proper inspection is as essential to special work, each item of which in the most extreme cases becomes an individual creation, as in highly standardized products, manufactured by automatic machinery.

The writer is opposed to placing the control of inspection at any time in the hands of those directly responsible for production, as is apparently done at the Bausch and Lomb Optical Company. The reason for this position is that the inspector is under pressure from two opposing directions—the need for quantity and the need for quality. One of the most satisfactory arrangements other than a separate inspection department, which is not often found, is to place the inspection department directly under the supervision and authority of the engineering department. In as much as the engineering department is directly responsible for the setting of quality standards, it is up to this department to see that such standards are attained. Such an alignment may eliminate the necessity of inspecting the inspector's work. The engineers are also in a better position to assist in correcting conditions which prevent the attainment of inspection specifications. Seldom is the engineering department given sufficient authority, responsibility, and scope for its activity. Care must always be exercised that conflict is avoided between the production and inspection groups. The conference plan, outlined by the author, is helpful in avoiding discord.

There are so many methods of inspection that it is difficult to lay down a hard and fast law applicable to all conditions. The author states provisionally that rigid inspection and low costs go hand in hand. This is not entirely true, as the law of diminishing returns certainly becomes effective in inspection work to a noticeable degree. In the final analysis the results to be obtained must be set against the *lowest cost* method of obtaining them.

B. H. Waterbury.[3] Many of the inspection methods, methods of establishing standards, factors influencing inspection, and inspection policies cited by the author, have their equivalents in other manufacturing activities than the one which he has considered. In the refining of petroleum, for example, inspection may be said to be one of the most potent factors in the maintenance of quality. This inspection begins with the crudes and continues through each process step to the finished product, whether that be aviation motor oil, cable saturant, fully refined paraffine wax, motor fuel, or other product. The development of special inspection apparatus has been necessary in some cases, as for making vacuum assay distillation tests, for determining the sludging properties of transformer oils, and for determining the resistance to emulsification of turbine oils.

Departmental inspection during the intermediate processing as compared with total inspection activities probably has a greater importance in petroleum refining than in most other industries. Standardization of all inspection instruments and master checking of inspection results, therefore, require close, skilled attention. Many of the larger refining companies maintain control laboratories whose work is closely coordinated with that of the Bureau of Standards.

Quality standards for many refinery products are established by recognized specifications. In the preparation of specifications there is, in the petroleum industry as in others, the necessity for the establishment of a rational mean between the ideas of quality sometimes held by customers and sales organizations and the urgency for low refining costs. In other words, as the author has suggested, in a desire to reduce sales resistance, certain product qualities, as for example, color and specific gravity, are sometimes disproportionately emphasized at the expense of refining costs.

With the majority of refiners the cost of inspection is an appreciable part of the total manufacturing cost, but an indispensable one in that it reduces other costs by enabling close control of operations, and in that it serves to maintain uniformly high quality of output.

R. T. Kent.[4] The question of inspection, like all other questions which arise in manufacturing, depends entirely upon the conditions surrounding manufacture. No hard and fast rule can be laid down for the inspection of a diversified number of products. The inspection system must be adapted to the particular manufacturing problem in hand.

There is no more important function in manufacturing than

[2] Cooley & Marvin, Boston, Mass. Assoc-Mem. A.S.M.E.

[3] Superintendent, Eclipse Works, Atlantic Refining Co., Franklin, Pa. Mem. A.S.M.E.

[4] General Manager, Bridgeport Brass Co., Bridgeport, Conn. Mem. A.S.M.E.

inspection. Faulty inspection means that faulty goods are going out to customers, inspected there and then returned to the manufacturer, who then has the privilege of paying the freight both ways.

In the organization of the inspection department, it is quite true that the inspector should be in contact with the man who is in charge of production. It should be the inspector's privilege to stop the work at any time that he finds it is coming through wrong. However, there is a development whereby a partial inspection can, with advantage, be put into the hands of the production men.

In our organization we have had a very elaborate inspection department, with process inspection in each manufacturing department. The process inspectors were entirely independent of the foreman. We found, however, that the inspector often had insufficient technical knowledge to enable him to correct faults in manufacture as they developed. The gap between the discovery of faulty products and the correction of the fault was considerable, resulting either in a large amount of spoiled work or of high expense for reclamation.

After a number of trials to eliminate the trouble, we developed the system of putting the process inspection squarely up to the foreman. The system evolved was that each operation, where trouble could occur, was inspected, the foreman making the rounds of the various machines in his department, inspecting the work as it came off the machine. If it was all right, well and good; if not, he stopped the work then and there. He would then ascertain what the trouble was and take immediate steps to correct it. After each visit of the foreman to the particular machine, the container in which the work was being placed, as it came from the machine, was set aside and moved away from the machine, the workman starting to fill a new container. If the foreman discovered faulty work on his next visit, the container containing the product was emptied and the product inspected 100 per cent. In that way we eliminated most of the spoiled work.

We have by no means eliminated the final inspection. Most of the products, before being sent to the customer, are inspected 100 per cent, depending upon the circumstances or quality of product.

W. F. Bailey.[5] In the writer's organization inspection is divided into three groups, two of which are under the manufacturing division and one under the Works Committee which will be dealt with later. Under the manufacturing group are the foremen of the various departments, who must go over the work in the department six times a day and carefully check it. It is purely a matter of inspecting the parts, the worker using the gage at the machine as a check on the work. The main inspection is under the manufacturing division also. All of these inspectors are in one room. A very simple conveyor system runs from each department to the inspection room to facilitate inspection of all the work. The work is so arranged that ten times each day the inspected material from one inspector is rechecked by another person, without the knowledge of the first inspector. A check is made for quantity as well as quality.

In connection with the general inspection, one man continuously checks up on the product. He will gather up a number of parts, and test them to make sure the work is right. In so doing he goes over a complete cleaner once a week. We also make a complete check on one per cent of our assemblies in this same department. We take a cleaner off the floor once a day, and take it to the tool room where every part is carefully measured. In this general inspection we try to catch the product at that stage where we can repair the article without spoiling it.

In the case of the motor, the winding is tested as it comes from the winding department, being checked for "stretch of wire," "open ends," etc. For instance, if the wire is stretched five per cent in winding it is noticed in the speed of the motor and corrective measures are taken. Before the armature goes to the dip, it is tested twice for "open shorts" and "grounds." That is a double inspection, two men checking on each other, because at that point we can correct most of the work, while corrective measures are impossible after it comes from the dip and the oven.

An interesting inspection is that of the beater bar or agitator. This is checked for the length of the beater bar, and extension of the beater-bar ribs before they harden. This part must be extremely accurately made, and it is given a 100 per cent inspection both before and after hardening.

The final inspection of the product is carried out by a group of inspectors functioning out of the jurisdiction of the production department and to a group known as the Works Committee inspectors.

This final inspection tests for wattage, speed, vacuum, lift of rug, adjustment to rug, and all appearances.

This group also makes a most accurate check on all incoming purchased material to make sure that the material meets the company's specifications.

The Works Committee inspectors answer to a group consisting of representatives from engineering, production, inspection, sales, service, and management, and of whom the general manager is chairman.

Through the service department inspection is also carried to the field. For instance, samples of dirt from California, Texas, and New York may be desired, and these men will secure the dirt prevalent in these territories direct from the homes. It may be found that dirt taken from a New York State home functions in the cleaner, but that the dirt from Texas will give a lot of trouble. Samples of dirt are sent in from these various places at certain intervals so that it may be determined whether or not the cleaners handle them properly.

Rugs are also distributed throughout the factory, placing them in the various departments where there is considerable traffic. These rugs are previously cleaned thoroughly, and they are 100 per cent clean before they are turned over to the inspection department. All kinds of rugs are tested to make sure that there is no type of rug that cannot be handled.

The question of incentive for inspectors has been mentioned by one of the speakers. The company is considering starting in its inspection department an incentive along the lines of a standard time system. Under this plan the inspectors will not only get their day rate but a certain percentage of the saving which they make. However, if some defect is found passing the first inspection, the inspection department which has passed it will be penalized four times the cost of inspecting the job. There will be an extreme incentive to speed up, making this saving in cost, but the whole saving is likely to be wiped out if the inspectors are not careful.

E. G. Quin.[6] In one branch of the Bausch and Lomb factory we have developed a wage incentive system wherein both quality and quantity are linked together with the emphasis on quality. The work is sent to the factory inspection department on whose report the operators are paid, based both on the quantity good and the total quantity produced. This inspection is entirely separate from the final or check inspection to which Mr. Graeper referred, which is not under the factory's direction. In order that there may be no favoritism in this factory inspection, the work of the different operators is arbitrarily sent through as that of operators Nos. 1, 2, 3, etc. In this way the inspector does

[5] General Superintendent, The Hoover Co., North Canton, Ohio.

[6] Bausch & Lomb Optical Co., Rochester, N. Y.

not know whose work is being inspected. Our final inspectors in the factory are the highest paid operators and we endeavor to promote our best operators to the group which does this inspection.

I would like to present a point for discussion which has not been touched upon. We will assume that both supervision and operators share in the wage incentive. What percentage of the penalty for rejected work should be applied to supervision and what percentage should be applied to the operators? Should the entire penalty be applied to the operators, should the entire penalty be applied to the operators and an additional penalty applied to supervision or should the penalty be divided between the operators and the supervision and if so in what proportion?

L. P. Arduser.[7] Methods of inspection depend to a large extent on the organization of a plant, and the articles manufactured. Inspection is first encountered, as a rule, in the purchasing department, which buys in accordance with more or less rigid specifications. The raw or partly worked material is carefully inspected by the receiving department as to quantity, and by that department or a plant laboratory, as to quality. This is true whether the material purchased is pig iron or seed clover.

The inspection department is frequently independent of the production department, and under a separate superintendent. The only real cooperation is between the superintendents of production and inspection, and a few of their department heads at the most. Inspectors pass on material after each process, using spot (about 10 per cent) inspection on parts such as rubber buffers, bolts, drawn parts, etc., and 100 per cent inspection on more important parts. What are called component units, and also final assemblies, are subjected to 100 per cent inspection, for "working qualities."

Parts made by automatics are given a running inspection by the set-up men. Small parts in process, after each process, are usually moved into separate inspection rooms. Large parts, hard to move, are inspected in the particular department concerned. The inspector's O. K. is necessary before any parts can be moved into stock- or be used in assembly. This inspection might be spot, or 100 per cent, depending on the article or component part considered.

Many component parts are moved into stock, to remain there for six months or longer. The reason is simple. A battery of automatics in two days can frequently turn out enough of a desired part to last a year. It can be seen that running inspection by the set-up men, and a further inspection by the inspection department, is necessary and an economy if "passed" stock is to be drawn out as needed. To take a battery of automatics, or only one, off of one job, set it up again for a temporary job, take it down and set it up again for the first job, is exceedingly expensive. This does happen sometimes, but it is not always possible to predict what kind of an order a salesman will bring in, and emergencies must be met. Better correlation of sales and planning activities will frequently prevent such a procedure.

In a certain electrical manufacturing plant, the inspection department, although independent of the production department, is nevertheless represented at all daily meetings of foremen, and also of department heads. Current troubles and differences of opinion are usually settled at the time by the engineering and inspection departments. The same system of inspection has been used for some years, and seems to be functioning well. This plant manufactures a complicated product, in which some 4000 different parts are needed in quantities of from 500 to about 40,000 per year. The various inspections vary from sighting along a line, to delicate electrical inspections with post-office types of bridges.

[7] John Wiley & Sons, Inc., New York, N.Y. Assoc-Mem. A.S. M.E.

In another plant, a sash and door plant, very little formal inspecting is done. Stair treads fit, or they do not fit. Since stairways are made up almost entirely by the same artisans, working from drawings, they do their own inspecting. Stock sizes of sash and doors are always correct to within a certain percentage. The carpenter is expected to use his plane on the job to make windows and doors work freely. Jigs, and even gages, are used more frequently in the wood industry, since quantity production, and long-distance shipments to consumers are more the rule than was formerly the case. Great advances have been made by the industry since engineers have been employed more frequently.

In still another instance, a radio plant employing some 6000 operatives had a force of about 150 inspectors. Costs were running up and competition was keen. Inspection was made on 100 per cent of the output, for both component parts and assembled units. The inspection department was independent of the production department. Production was irregular, sales disappointing, and returns from customers entirely too frequent. In a reorganization, the inspection department was cut to about forty. The foremen are now responsible for the quality of component parts. Their inspection is subject to a spot inspection by the inspection department. Whenever a certain small percentage of "no-pass" parts is noted, the foreman in charge of the department making that part is told to check the matter, and stop production, if necessary, until matters are righted. A final inspection of assembled units, for "working qualities" is made by the inspection department. This inspection is 100 per cent and is subject to a spot reinspection by the head inspectors. The inspection department, of this plant, is now present at all planning meetings, and confers on all purchases, on the manufacture and design of the product, and the design of new tools. The inspection department has a voice in manufacturing, and in the determination of policy.

Some engineers insist that inspection shall be absolutely independent of production, and that this function, at least, must be kept separate from all other functions of manufacturing. This may be correct in some instances, but it is not correct in all. Competition and costs determine the matter, to a large extent. Some leaders in business and industry are beginning to think that we have functionalized too much, and that the foreman should again be a foreman—at least as much as is consistent with retaining the benefits of the division of labor, modern automatic machinery, and large-scale production and sales.

The writer regrets that he cannot name specific plants, or the "some leaders" in industry, but it can be seen that for one in his position, who obtains more or less confidential information—often without asking—it would be unethical to divulge any names. The instances cited, and more, have all come under the writer's observation, either as an employee, or a representative of the publishing house with which he is connected.

G. J. Hopkins.[8] The similarities of inspection methods of all materials are, as the author pointed out, of two kinds: first, laboratory methods determining the quality of the material, which would cover the dryness of wood and chemical and physical properties of cast iron, as well as the purity of optical glass; second, the special gage-and-fixture method of determining sizes within exact limits. The only difference in these methods as applied to rough and fine goods is the width of the limit or tolerance allowed, and a consequent variation of refinement of the tools applied as measures.

However, there is one thing which does differ radically as between coarse and fine products, or rather between articles of

[8] McCray Refrigerator Corporation, Kendallville, Ind. Mem. A.S.M.E.

ordinary utility and precision instruments. This difference is in the amount of judgment required on the part of the inspection department to make sure that the policy of the house is carried out to the letter in the product offered the public.

The author has called attention to the effect of lapses from quality on the sales resistance, and also the effect of an increase of quality on increasing the cost. It would seem that in the case of precision instruments, very exact specifications can be drawn, but when we come to less exact items such as are affected by the public taste—let us say in the finish of automobiles—or the length of the useful life of the article, the policy of the house must be more or less governed by the kind of market in which it expects to sell, and the competetive conditions of that market. The salesmen are the men that eventually come into contact with the proof of the quality of the goods. They bring back to the house the public's judgment in the shape of reports to the management. These may be in the form of enthusiastic boosts, or neutrally written on a form, telegraphic, or verbal and profane. The greatest question, and the one that becomes most important as competition becomes keener, is "What method can be utilized to translate this mass of variable and often conflicting information into sound judgment for the inspection department to apply to new goods in process?"

In the writer's experience covering both kicks and plaudits in regard to a variety of goods going into the hands of users who are in some cases farmers and some mechanics, and some into the hands of retail stores for resale, we have never discovered a substitute for personal first-hand information, obtained by sending the chief inspector out into the field to determine for himself how high the quality must be carried to be satisfactory, and how closely the article must be trimmed to stay within its price class.

In other words, the writer's most poignant experience with inspection, both good and bad, has borne upon the chief inspector's actual knowledge of the goods in the field. It would, therefore, seem that in a highly organized production plant, the inspector should be no less a personage (except perhaps in the matter of organization ability), than the man in charge of the manufacture.

W. L. WALKER.[9] The author points out the need of the inspection of products to insure the maintenance of standards adopted by the manufacturer. Naturally, the relative amount of inspection found necessary in the various industries will vary between wide limits. In raw materials the chemical composition may be the most important consideration, while in finished products technical accuracy, strength, beauty, etc., may all count to make up the required standards.

Every manufacturer desires to make the inspection problem as easy as possible and to avoid the inaccuracies of human judgment wherever practicable. In order to accomplish this, products are standardized as far as possible, and the manufacturing operations are performed as far as it may be economical on automatic or semi-automatic machinery, where the required limits of accuracy are determined by the machines and are out of control of the regular machine operators. With the great increase in productivity of factory operators who are paid according to some well-planned wage incentive system, it is essential that conditions for accurate work are made as nearly fool-proof as possible. This is not intended as an argument in favor of hourly or daily wages to operators, as contrasted to a wage incentive system. On the average, better work will be performed by operators who are paid for their production by some wage incentive system whereby their rewards are largely under their own control, than by operators who are paid hourly or daily wages for their time.

[9] Asst. Gen. Mgr., Washburn Co., Worcester, Mass. Mem. A.S.M.E.

The transition from the artisan who had the interest of his own artistic expression in the products of his work, to the present-day factory operator, who may have only one of the numerous operations to perform on a product about which he knows practically nothing, has lowered the appreciation and responsibility for accuracy in work. Therefore, inspection is necessary, and the aim of the management of any industry is to control inspection as far as is possible by mechanical devices. Inspection costs, if not watched carefully, will increase beyond the limits allowable in any reasonable manufacturing budget. It is, therefore, advisable to study the needs at frequent intervals to determine just how far it seems practical to go in inspection work. In the business discussed by the author, it appears logical that a highly developed system is essential. In most of the industries with which the writer has been associated, the majority of the products manufactured are utilitarian, requiring few, if any, technical specifications of accuracy. Where technical accuracy has been necessary, certain mechanical devices have been developed which reduce most of the inspection tests to a routine, or chemical tests have been made by accepted methods of chemical analysis.

The author states that, where possible, the inspection operation should be made productive, certain other operations being performed while the inspection is made. This has been the policy in many industries.

The author also states that the chief inspector is responsible only to the management, in order that he shall have a free hand in determining quality. This is always advisable. Also, the policy of the inspectors should be not only to determine what is wrong with an article, but to investigate sufficiently to ascertain, if possible, why the product has become defective and, where practicable, to cause such changes in conditions as to reduce to a minimum the liability for the same kind of errors in the future.

The last quarter of a century of productivity has shown what the machine age could do in supplying human wants. In order to supply the enormous demand at the prices necessary, constantly improved mechanical equipment has been invented. Perhaps the most important achievement has been the development of modern production methods, whereby the men and women in industry have been able and willing through increased reward to show what they could do to increase output. The result of this has been that the production per person is undoubtedly larger now than at any time in history.

It is natural that the emphasis on production in many lines (not all) should have a tendency to detract from the interest in the art of industry. In an attempt to find a way out of this "profitless prosperity," suffered, perhaps, by the majority of concerns in competitive industries today, some are turning their attention toward products which will not only be satisfactory from the standpoint of utility, but which also will help to awaken and satisfy the artistic temperament of the customers. The function of beauty, which has long been partially or wholly ignored in the design and manufacture of many articles, may become the most important problem of the designer and manufacturer. If this comes, as it probably will, there will be another problem of inspection with which the average manufacturer is not familiar. Such inspection undoubtedly will call for the services of men and women who have a natural sense of harmony and artistic expression as well as technical training in the particular industries where they are employed.

With the designing of artistic products, and their manufacture in quantities under modern production methods so that costs will be low enough for a wide distribution, the management of the future must of necessity understand the detailed processes of production, administration, and distribution in order to keep the proper balance. It is to be hoped that with the development

of art in industry, coupled with the necessity of adequate technical inspection, as well as inspection for beauty and design, the control of production may still insure sufficient output for each employee or machine-hour to insure high wages and low costs.

W. L. Coley.[10] In the manufacture of precision instruments, such as made by the writer's company, quality is the most important essential. The users demand 100 per cent perfection, and for that reason we have never attempted to introduce piecework in our manufacturing. Our inspection is under the jurisdiction of an inspection committee, consisting of one chief inspector, production superintendent, and a member of the engineering department. The shop superintendent is responsible for standards. The committee has functioned for three years, and its duty is to anticipate trouble and prevent it. Another device that we use is a regular complaint system, which brings into the plant the ideas of customers on an instrument. The complaints are made in the form of a report, which is handed to those in the factory who may be responsible. The complaints are analyzed and answered. This system has enabled us to uncover many things which might have caused considerable trouble.

C. J. Roberts.[11] The writer is interested in knowing how the rates for inspectors are set, how they compare with the rates for operators on the machines, and whether the rates are set in comparison with the machine piece rates or with other standards, such as hourly rates. The type of inspector particularly in mind is that one who does not have to be highly qualified, say one who has been transfered from a shop job to the inspector's job. For instance, on screw-machine parts, where there is considerable routine work in the inspection of that product, girls are largely used as inspectors. What is the author's system for fixing rates for such work?

The Author. In reviewing the discussion, it is found that some difference of opinion exists as to the extent to which responsibility for maintenance of standards of quality should be entrusted to production departments. There seem to be two general plans of inspection in use. Under the one, all inspection is carried on by a separate department which is usually independent of the production organization. Under the other plan, responsibility for quality to some degree, especially where parts and processes are concerned, is assumed by inspectors reporting to departmental foremen or division superintendents. In addition, inspections and tests of the finished product are made by a separate department whose head is responsible to the management or perhaps to the engineering department.

At the plant of the Bausch & Lomb Optical Co., the second of these two general methods is in use. Parts and process inspectors are responsible to department foremen. In most of the manufacturing divisions separate inspection departments have been set up. The heads of these departments are responsible to the division superintendents. They carry on an inspection of parts and processes and in some cases, of finished product, but whenever the finished product is involved, their work is subject to spot inspection and control of the final inspection department which is an independent organization responsible only to the management.

The theory behind this arrangement is that it is easier to obtain desired quality when its maintenance is as much the responsibility of the production departments as is that of cost and quantity. It should be remembered that the establishment of standards is not under consideration in this connection, but only the matter of carrying them out in the finished product. Let it be assumed that standards of quality have been established for the production departments. It now becomes their duty to put them into effect. However, the final inspection department is the controlling and guiding agency which has been instituted to enforce adherence to the standards which have been set up. This department, furthermore, makes all working tests, on a basis of a 100 per cent inspection where finished instruments are involved, as has been fully explained in the paper under discussion. Through this plan a double check on quality is obtained such that, if faulty or defective merchandise should happen to be sold, both the inspection department and the manufacturing departments may be held responsible under conditions where neither may pass the responsibility on to the other. Satisfactory results have been obtained through this plan.

It is quite likely, however, that other methods may be equally effective in maintaining desired standards of quality and that varying conditions existing in different manufacturing plants may make their adoption and use desirable.

In reply to a specific question, it may be stated that no general rule is applied in determining the wages of inspectors. This cannot be done because the variety of product which must be inspected calls for various degrees of skill and judgment on the part of inspectors. For much of the routine work female inspectors are employed. These are frequently chosen from operators in the manufacturing departments because of their experience with the work, their higher than average intelligence, and their ability to use judgment. Such transfers are considered as promotions with resultant higher wages. The more highly specialized inspectors engaged in instrument inspection, in most instances, have had previous experience in manufacturing departments as skilled workers. They have been chosen because of their aptitude, because they have a temperament which makes them suited to the work of inspection. Their compensation, consequently, is higher than that of the workers whose product is being inspected.

The validity of the statement that rigid inspection should result in low cost has been questioned on the assumption that the law of diminishing returns becomes effective. The writer's viewpoint in this connection is based on the supposition that the manufacture of a given article is undertaken after definite standards of quality have been established and that these standards have been maintained in the finished product. It is reasonable to suppose that minimum costs may be brought about under these conditions through rigid inspection and its by-products. If, on the other hand, standards of quality have not been set up at the beginning of manufacture, it is equally true that lower costs will result if no inspection is instituted, but at the sacrifice of quality.

[10] Leeds & Northrup Co., Philadelphia, Pa.

[11] Chief Insp., Leeds & Northrup Co., Philadelphia, Pa.

# Coordinating Wage Incentives and Production Control

## An Outline of the Principal Features of the Bedaux System

By OSCAR GROTHE,[1] CLEVELAND, OHIO

THE White Sewing Machine Corporation owns and operates the White Sewing Machine Company, the Domestic Sewing Machine Company, and the Theodor Kundtz Company. The metal parts of the sewing machines are built from the ground up, with the exception of the foundry work. The cabinets, or woodwork parts, are built completely, including the manufacture of veneers and panels and from rough lumber on. The school work, opera chairs, and auditorium seating are built complete, with the exception of foundry work. The church work, including pews, altars, and all the other furniture, is a straight jobbing business and built from the ground up. The various articles are marketed through different kinds of channels, that is, through the corporation's branch offices throughout the country, through dealers and jobbers.

The Bedaux plan is used in the operation of the manufacturing division.

In order that all may think and talk alike, as nearly as possible, in the organization, we combine together as production control (which is responsible as to where, when, and how many from the time of the inception of their requirements until leaving the factory) the following departments:

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| Planning | Cost |
| Scheduling | Purchasing |
| Dispatching | Receiving |
| Timekeeping | Supplies, raw material and finished parts stock rooms |
| Payroll | |

Every one in industry is attempting, with varying degrees of success, to balance capacity with requirements, to establish and maintain control of raw, in-process, and finished materials, as well as labor and overhead, by means of some kind of plan involving scheduling, dispatching, etc. It should only be logical, whereever possible, to use all the records or measuring devices which may have been already established for other uses to accomplish this end, and thereby reduce the burden. For instance: Many companies make careful time studies of all operations, at quite an expense. In many cases they use this information for the payment of wages to the direct labor only, whereas this same information may, with slight additional work, be used for the payment of indirect labor, for cost records, budget, and other controls.

The foundation of our measuring stick or common denominator is a unit called the "B," which consists of a fraction of a minute of effort plus a fraction of a minute of compensating relaxation, always aggregating unity but varying in proportion according to the nature of the strain. In other words, it corresponds to the effort developed by a man working under normal conditions at a normal rate of effort for one minute of time. The average number of B units developed or produced per hour (or B-hour) is the measure of the labor rate of accomplishments, whether it considers the individual, the department, or the plant as a whole.

Generally speaking, and through the use of the B unit, control is established to give actual performance against standard expectations, and to analyze the differences. This enables those responsible to eliminate those differences which represent labor waste on such items as operators below standard, excess set-up, lost time, re-operations, and repairs or excess indirect labor. The control of production is attained through the application of standards, expressed in B's, to all forms of labor.

The B standard for any one operation represents the amount of labor, or energy, necessary to perform the operation correctly under existing conditions. It corresponds to the time in minutes necessary for a normal man, working under the existing conditions at a normal rate of speed and effort, to perform the operation correctly.

Planning of production simplifies itself to the relating of capacity to B requirements. Alterations to plans are treated in terms of the same unit, eliminating many of the burdensome details.

Instead of planning that machine No. 363 must on a certain day turn out operation 3 on 300 pieces of part 7, operation 1 on 450 pieces of part 210, operation 7 on 2500 pieces of part 16-A, and then figuring with all details at hand whether machine 363 has the physical capacity to do this, the planning department, knowing how many B's the machine is capable of absorbing in one day, assigns to it only as many B units as it can absorb. We have established, therefore, a measurement of human effort similar to the horsepower or watt.

In estimating bench-space requirements or capacity, again we use the same means of determining this as in the case of machine-hours, determining what the schedule requirement of B's may be and the capacity, also, for storage space. After having determined the requirements, B values are used for the purpose of determining how much storage is necessary to maintain the proper schedules, as the length of time required in process is definitely known. This is also true regarding containers of various types and kinds, of course always being careful to have them in convenient multiples whenever possible, for counting.

Dependent upon whatever the requirements of the particular institution may be, this information can be compiled for any individual machine, bench space, storage space, or container for any department, any particular type of article, or any kind of operation, group of parts, group of operations, or for the plant as a whole. It is a simple matter through this method to find out how many screw-machine B's of a certain kind are required, and again, how many are available, and so on, with drill presses and any other equipment.

For instance, in the cabinet-assembly department, where different combinations of styles are assembled on different days, and the units vary as to the amount of man power required for each, it is a simple matter to take the total schedule for any given time, whether one week, two weeks, or a month, and reduce this schedule to its B content by departments, and (or) by kinds of work, whether sanding, assembling, finishing, etc.; and then to take this total B requirement of any kind and reduce it to the daily schedule, and, in turn, each day compare the actual production with that schedule.

It would, of course, be impossible just to have a record of pieces as the department may be working one week on parts which require a small amount of labor, and the following week be

[1] Vice-President, White Sewing Machine Corp.

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working on some parts requiring double the amount of labor. The second week they might find themselves behind in schedule, whereas they may have thought they were overmanned. We have, in the past, had foremen come to us, some to say they were overmanned, and some undermanned just because their list of parts or operations on their schedule appeared to be either caught up or behind; but now we can definitely tell by the B schedule and B's produced just what is required and we do not carry an excess of help in the various departments, as the man power required is figured down to the minute.

The problem of containers or shelving is handled in much the same way. Before we invest in additional equipment or dispose of some of the capacity available, we check the requirements, using B values of capacity and requirements as one of the measuring devices. Machine capacity, as previously mentioned, is also handled in about the same way, and we very frequently find that by changing the routing, or moving a machine, or sometimes both, a material saving can be effected. We are able to tell this by the B capacity rather than by machine-hours. At the same time, we know whether or not we are getting the returns from our investment and equipment by our B-hour record, that is, by a comparison of how many B's per hour are produced with what should have been produced.

This same B unit is also used for cost records. To obtain standard costs the base or hourly rates on a given operation, group of operations, or department, are divided by 60 (as there are 60 B's per hour in a standard performance). This, then, would give the standard cost per B. Then the B's produced divided into the money spent for direct labor gives the actual direct cost. The B's produced, divided into the indirect labor gives the actual indirect labor cost. The B's produced can also be divided into the other overhead items, separately or as a group, as the particular industry or company may require.

In the case of re-operations or repairs, as well as scrap, we again determine the B cost on the items for comparative purposes of one period for various departments against another. This gives a good barometer as to whether progress is being made or not. In the case of supplies, such as sandpaper, drills, and other items, it is easy to equate the use of these supplies against the B's produced on the various operations. In some cases we pay incentives for the savings of these supplies.

It is also a comparatively simple matter to make ratios of indirect time to direct B's produced, taking into consideration supervision, sweeping, trucking, and practically all other factors of indirect work for a given department. This same applies to set-up time, all measured in relation to production. The greater part of the information is figured each day for payroll purposes, which is essential for a proper labor control. One of the features of the entire plan is that with just a little additional work the various items mentioned, and many more, can be measured, and the entire organization is educated to think and talk in the same terms or language. This makes it easily possible to shift help from one department to another, to combine the work of various departments and reduce the force to a minimum, and to know whether the minimum is being reached.

The combination of these various data then makes it possible intelligently to plan, schedule, and dispatch the labor, material, and equipment as to where, when, and how many; and makes available most of the information necessary intelligently to budget and quite accurately to predetermine costs.

If, without compelling undue mental effort or complicated calculations, supervisors can be given the means to know exactly what is being done, compared with what can be done, and to know the true measure of usefulness of their men and equipment, the real value of their gains and of losses, the true measure of themselves in comparison with other men of its class, these supervisors may be counted upon to work with all their strength toward any improvement of conditions that will increase the measure of usefulness of their men and of themselves.

Give to industry the use of a common term, a constant unit of measure that places a true value on all work done, on all men employed—labor or supervision—giving the exact extent of all gains, losses, and errors, controlling all changes in schedules and processes, all expressed in a manner easily understood, and permitting, through its simplicity, a continuous grasp of the entire picture, and you will automatically transform useless efforts into useful ones.

## Discussion

H. O. Stewart.[2] Of exceptional interest is the recognition given to indirect labor in this paper, which brings out the point that indirect labor has an important part in assisting production. However, numerous workingmen in various plants, using the system described by the author, cannot see the justice of having deducted from their earnings a portion of what they earn on their increased production for the purpose of paying indirect labor. They feel that it is unfair, and of course that in turn is reflected in the quality of the product. In one plant the number of units requiring "reprocessing" increased from 10 per cent to 40 per cent after this system had been installed, and the foremen seemed to see very little hope of decreasing the amount of imperfections.

Why should not the indirect labor incentive be paid from the saving in overhead instead of somewhat at the expense of direct labor, inasmuch as the overhead is reduced whenever the production is increased?

C. C. Shipman.[3] When the organization with which the writer is connected installed the Bedaux System, a direct departure was made from former Bedaux installations in that the premium paid to the indirect labor as an incentive was paid by the company and had no influence whatever upon the wages paid the direct labor. The amount of premium paid was based on premium B's developed in the department and was a percentage of the base-rate earnings.

At the time "Bedaux" was installed, premium was only paid as an incentive for labor effectiveness; later it was found desirable to influence this premium by accomplishments on control of waste, machine maintenance, small tools, and supplies, quality of product, and cement and oils. Operating budgets were set on these various functions and the progress collected with the labor on the "Bedaux" analysis sheets, showing labor effectiveness and labor effectiveness modified by expense items. Premium is now paid on a modified application.

The standards set are workable, are competitive between departments, and have changed the viewpoint of our foremen to that of managers. The scheme is psychological, and has created interest which has resulted in the development of the operating personnel.

During the first year in which this system was used the above items were reduced to an appreciable level, resulting in savings to the company many times the cost of the premium paid.

Martin Keller.[4] The laborer after all is the important factor in the cost and production of a product. He is a human factor. The writer's idea is that if we have a superman who can earn 50 per cent more than the average, he should get his 50 per

[2] Production and Cost Manager, 600 Harvard Street, Rochester, N. Y.

[3] B. F. Goodrich Rubber Company, Akron, Ohio.

[4] Oneida, N. Y.

cent increase. In this way he has a very definite incentive upon which to put forth his efforts.

Under incentive plans, the Bedaux system, etc., the employer does not pay all employees what they earn above a certain average. Some of it goes to the overhead workers, or management. It would seem an injustice to the superman to have part of his earnings taken away from him. It destroys the incentive to become a superman.

The writer cannot picture obtaining the maximum production from the men by means of the Bedaux system when the men do not receive all of their earnings.

It would seem that the morale of the whole organization would be affected when the men are not paid all of their earnings. Or to put it another way: on the piece-work basis they are earning a certain amount of money, depending on their speed and ability, and if another system like the Bedaux is installed, by which they will not receive as much, how can the faith and the confidence of the organization be kept?

W. R. McCanne.[5] When the Stromberg-Carlson Company began the installation of the Bedaux system in 1921, there was no desire to reduce wages. On the contrary, it was desired to keep the earnings where they were and at the same time increase production, so as to lower costs. The plant operated partly on day work and partly on piece work, and not more than 50 per cent of the current production was covered by piece-work rates. Under those piece-work rates the employee was being paid for a full 100 per cent of the actual production.

The Bedaux Company's recommendation was adopted that a standard task be assigned on every operation, and in excess of that standard task, 75 per cent of the value of the production should go to the productive worker. The balance of the extra production should go to the foreman, assistant foreman, supervisors, machine and maintenance men, machine set-up men, truckers, and those who assist in providing the right conditions for increased production. Many workers were changed from the 100 per cent plan to a 75 per cent plan, and in about 90 per cent of the cases the employee's earnings increased.

To cite a particular instance, two good men who had worked under piece rates on the assembly of telephone generators for years were called upon for an increased task. They said that it could not be done. After using various expedients, we finally enlarged the size of the tray which held the generators from a capacity of 25 to a capacity of 30, and we found that they performed the operations on the same number of trays they had done formerly. In that way we increased the production to the point desired.

In the final analysis these plans are just tools. Their success depends upon the application, the seriousness of purpose, the diligent follow-up that is put behind any one of these plans.

[5] Stromberg-Carlson Telephone Mfg. Co., Rochester, N. Y.

The Author. It appears from these discussions that their writers have somewhat strayed from the topic under discussion, that is, "Coordinating Wage Incentives and Production Control."

The discussion seems to be leading into the merits of the Bedaux plan of wage incentive for the operator; however, I shall be glad to give my version in connection with these discussions.

I have at no time said, nor believe, that we are not paying operators everything that they are earning; on the contrary, it is our intention and we do feel that we are paying the operators everything which they are actually earning. As Mr. McCanne explains in his discussion, practically all operators under this plan earn and receive more pay than under previous plans. The mere fact that the particular operator has produced more than in the past is not sufficient proof in itself that the operator had earned at the same ratio, inasmuch as there are others in the particular department that have assisted and helped in such a way to make it possible for this operator to turn out more work, and it was not necessarily by his own efforts alone. I am fully agreed, and always will be, that each individual shall receive all he earns, but I do not feel that there is a constant ratio between earnings and production at all times.

Referring to Mr. Stewart's discussion regarding quality: It has been the general experience with all types of incentive plans that the highest producers average the best grade of work, regardless of whether this be the Bedaux plan or any other, and it would be my opinion that there was something radically wrong with the management in the particular case which he cites where "reprocessing" had increased from 10 per cent to 40 per cent due to an incentive wage plan. Perhaps prior to that time it was a case of not having the proper records or measuring devices for bringing this waste to light, and in any case I should think it a sign of weakness to take the foreman's word alone as to the possibility of decreasing the amount of imperfections, as it is quite a human weakness to make it easy for oneself.

Mr. Shipman, I think, very plainly brings out the point that this particular system, that is, the Bedaux plan, has very materially reduced the waste in his institution and made a considerable saving in cost. However, no plan alone will do any of these things—it requires good management with any plan; and as Mr. McCanne states, the plan is simply the tool or measuring device for management to use to accomplish its purpose.

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# Control of Factory Overhead

By H. G. Perkins,[1] Detroit, Mich.

*The control of factory overhead is almost synonymous with good management. The so-called uncontrollable items of overhead, as well as the controllable items, are amenable to downward adjustment from many different angles.*

*Tactful discipline of executives, the education of supervisors in cost of materials and service of their own departments, and study or research to determine better and cheaper materials and methods, are essential to expense control.*

*Expectancy of promotion, personal recognition and appreciation by the higher executives, assignment of added responsibilities, and payment of bonuses to executives, often greatly influence the esprit de corps of an organization.*

*Uniformity in output is a factor of greatest importance in the standardization of costs, and for this reason a rate of production not in accordance with current demand for the finished product is often advisable so that costs may be maintained at their proper levels.*

*A properly designed and vigorously administered budget-control scheme is a very powerful means of overhead control, and should cover such points as the attainability of quotas set, a voice in setting quotas by department heads, the provision of cost data for guidance of department heads, the establishment of well-defined standards of operation for various departments to act as checks on estimates and means of forecasting future performance, and the careful comparison of results with quotas in order to determine possible future economies.*

At first glance it would appear that the proper introduction to a discussion on the control of factory overhead should logically begin with the listing of all items of outlay charged to the overhead accounts, and proceed by a process of elimination to the selection of those items that may be classed as controllable, thereby eliminating from consideration such accounts as insurance, depreciation, and taxes, and give thought only to the so-called controllable group, including the well-known items of labor, material, supplies, and sundries.

Undoubtedly there is a widespread tendency to accept the uncontrollable elements of burden as necessary evils to which we must supinely resign ourselves. But before surrendering without a struggle, nothing will be lost if this viewpoint is challenged for the moment. Considering the element of depreciation, for instance, and assuming a flat monthly rate has been established on a most intelligent and scientific basis, has not management frequently taken the attitude that it has done well to set this rate at a figure assuring conservative and safe current cost, and at that point dismiss the matter by assuming that nothing else remains to be done? But is it not a fact that surprising possibilities for reduction of this charge are often revealed by closer study and more inquisitive analysis? Many institutions on a sound footing could discover hidden possibilities for reduction of depreciation charges if they had a more intelligent understanding of the extent to which these charges were influenced by the character of their maintenance and repair work, by the quality of their equipment and tooling, and by the diligence displayed in following the old axiom that a stitch in time saves nine.

Similarly, with insurance, is the significance of strict safety regulations, adequate plant protection, and elimination of hazards fully appreciated so far as their influence on insurance rates and amounts is concerned?

Perhaps this aspect of the question of overhead control can be disposed of with the statement that management errs if it accepts the term "fixed charges" too literally, and is guilty of negligence if it does not make an exhaustive analysis of every condition that influences this fixed-charge class of accounts.

### Weapons Available for Controlling Expenditures

When consideration is given to the controllable group of overhead accounts, it would seem that a proper approach will be made by listing the several weapons available for controlling expenditures. Without attempting to classify or name them in the order of their importance, these weapons will be given some brief comment.

*Discipline* undoubtedly takes a place somewhere in the picture. It is not difficult to conceive the disastrous results which must follow in an organization that does not feel the weight of the management's displeasure when excessive or unwarranted expenditures have been made. The moral effect of discipline must not be discounted. It might be said that discipline is of a negative value because it employs punishment for past shortcomings; but its influence on future actions is not to be underestimated. The spanked child does not immediately repeat an offense. So we may say that discipline is entitled to some measure of consideration in the control of overhead.

*Education.* Another weapon of somewhat different character, whose importance is often not fully appreciated, may be named by the term "education." Too often management has been inclined to exercise discipline, when as a matter of fact the fault lay at the management's door because responsibility given to an individual was not accompanied by instructions which would make that individual fully realize his duties or the possibilities within his grasp. It is an actual fact in the author's experience that a surprising number of shop foremen do not know the price of lubricating oil per gallon or the value of the perishable tools used in their departments. Management could do nothing more effective to control overhead than to educate its supervisory class to the proper interpretation of material things in terms of the dollar. The man who spends his company's money in actual purchase of incoming materials clearly visualizes the amount he obligates the company for. Is there less reason for a clear picture in the mind of the one who consumes those things? Educational work along this line is certainly an essential part of any well-rounded procedure on the control of overhead.

*Research.* A somewhat similar vein is the matter of research. Tireless study and investigation will often reveal possibilities of reduction of expenditure seemingly at an economic minimum. The author has seen many economies affected merely because of refusal to accept the current condition as being the last word, despite its apparent soundness. A persistent challenge of these apparently acceptable expenditures sometimes reveals surprising results in the way of substitution or elimination. As a case in point, the author knows of an instance where the substitution of crepe paper for cloth used to protect automobile interiors during assembly has resulted in a saving amounting to thousands of dollars. The surprising thing is that the experiment was not thought of years before its actual introduction. It may be stated as an uncontradicted fact that the control of overhead is incomplete if study and research are not in constant use.

[1] The Murray Corporation of America.

Contributed by the Management Division and presented at the Annual Meeting, New York, December 5 to 8, 1927, of The American Society of Mechanical Engineers.

*Incentives.* Another of the very important (if properly handled) means of reducing overhead is through the medium of well-regulated incentives to those responsible for results. One form of incentive which has come within the notice of all of us is the expectancy on the part of the executive of promotion in due time. When he accomplishes something a little out of the ordinary, or when he spends a considerable amount of excess time on the job—more than he is expected to do—or when by extra effort or unusual ingenuity he accomplishes an especially noteworthy result for the company, he is subconsciously thinking of promotion. This form of recognition is expected by all of us as we become more valuable to our employers through the acquiring of experience and knowledge of the particular work with which we are entrusted.

We have all seen the man of mediocre ability suddenly become transformed into a veritable dynamo of energy and endurance, solely because of a promotion, which though perhaps well deserved, was a little unexpected. It cannot be overlooked that the likelihood of promotion exerts a very great influence upon the will to accomplish and the desire to make a showing in some particular field. However, in order that promotion may be depended upon as a means of keeping executives on their toes, there should be a recognized procedure, a well-established and well-understood cycle of cause and effect, with cases in point from time to time judiciously brought to the attention of fellow-workers in a way that keeps them believing in the justice of the management with respect to this form of recognition for faithful and loyal service.

Another form of recognition which is seldom given credit for its real value as a means toward reducing manufacturing expense is the recognition of an employee by words of praise publicly given, or by suitable titles judiciously bestowed, or by giving an individual a certain responsibility which places him in the limelight among his fellow-workers and makes it a matter of pride for him to bring his individual accomplishment to the highest point. The author has seen many an indifferent worker suddenly take an amazing interest in company affairs by the simple means of a personal item in the shop newspaper. Even as simple a matter as being recognized in the shop by one of the higher executives has had this same effect, and a wish personally expressed by them many times produces results that could not be attained in any other way. Pride in this matter of recognition by those in the high places is indeed an important factor in causing employees—the executive no less than the worker—to take a keener personal interest in the economies and savings which are possible on his job.

*Bonuses to Executives.* Still another form of incentive which never fails to produce results when fairly and justly applied is a bonus to responsible executives. One outstanding criticism of bonuses of this kind, as they are operated in many cases, is the fact that the bonus has not necessarily been given to those most deserving of it. As it often has worked out, the individual who could put up the best appearance before his superior or who managed to get public recognition for some of his accomplishments, was the individual to receive the lion's share of any bonus money that was being distributed. An executive bonus, to be successful, must recognize ability and accomplishment only. That the individual be a personal friend or favorite of his superior, or that he succeed in advertising his accomplishments, must not be a prerequisite to receiving a bonus. The bonus plan must be worked out on an equitable basis, arranged to reward most those whose responsibilities for results have been greatest. Perhaps a brief description of an executive bonus plan designed to reward the individual executive in proportion to his accomplishments, as well as to foster a spirit of cooperation between department heads, would be in order at this point. The purpose of an executive bonus is, of course, to arouse keener interest in the financial success of the enterprise, and to induce each individual to do all in his power in his particular sphere of activity to increase profits. In as much as the amount of net profits is tangible evidence of the effectiveness of the endeavors of executives and supervisors, it follows that the net profits should be the basic element of the executive-bonus plan, and that the amount of the bonus shall bear some relation to the volume of net profits. Therefore, as a first consideration in the payment of an executive bonus, the profits available for a bonus after satisfying dividend requirements, proposed increases in fixed assets, required increases in working capital, and reserves for contingencies, must be ascertained. The plan in mind contemplates that in the event there are profits available for bonus, a base bonus of percentages of annual salaries varying with the individual's classification be paid for a range of net profits from the minimum at which it is considered proper for the company to pay bonus, up to a probable maximum. Having determined the base bonus rate for each of these classes of executives, it is arranged that adjustments will be made for individual performances. These adjustments will be modifications of the base bonus, either up or down, depending upon the performance of the individual in relation to certain fixed standards. The fixing of these standards is a comparatively simple procedure and will be outlined presently.

The first step in the determination of executive classifications is to divide the executives into a number of groups, classified according to their importance in the organization, or the responsibility with which each is charged. The percentages of bonus payable vary with the amount of profit and with the classification into which an executive falls. For any known amount of profits, the percentage of bonus for each class or group of executives has been established. This percentage, multiplied by the employee's salary, gives a base bonus, which is modified in accordance with the performance of the executive on the basis of the efficiency of the activities under his supervision. This includes three main items: namely, direct labor, the expense of indirect labor, and the use of maintenance materials and supplies. The figures measuring each one of these factors are readily available, as well as the standards for each one of these factors; that is, the amounts of moneys which should be expended in proportion to the production accomplished for each item. In the Chrysler Corporation these figures are obtained through the budget-control routine, and require no computation over and above that ordinarily made for budget determinations. Each of these factors in any given department is given a weight in relation to the other factors so that the totals in every case amount to 100. For instance, in a sheet-metal pressroom, direct labor might be given a weight of 60, productive labor a weight of 33, and supplies and maintenance expense a weight of 7, the total of these weights equaling 100. Then an efficiency rating for each factor is determined by dividing the standard or budget figures for each expense item by the actual expense for the period. The result is then multiplied by the weight of that factor, as just given, to get the adjusted weight for each factor, and the sum of these adjusted weights is the resulting overall efficiency of operation for the responsible executive. For example, it might be determined that direct-labor efficiency is 120 per cent of standard, that non-productive-labor efficiency is 90 per cent of standard, and that the use of supplies and maintenance showed an efficiency of use of 95 per cent of standard. We should then multiply each one of these efficiencies by its corresponding weight factor given above. In this case, the figures would be 72, 29.7, and 6.65, respectively, for the factors in question. The total of these figures, or 108.35 per cent, represents the executive's overall efficiency in the administration of his department. Next, let us assume for a certain amount of

net profit that the base amount of the executive's bonus would be 5 per cent of his salary. The actual bonus rate would then be determined by adjusting the base bonus rate of 5 per cent to correspond to an efficiency rating of 108.35 per cent, or by multiplication of these two figures. This resulting adjusted bonus rate multiplied by the executive's salary gives the amount in dollars and cents which the executive will receive as his yearly bonus. From this it is seen that the executive has something to do with the amount of bonus which he receives. By properly administering the affairs of his department, he increased the amount of bonus which he was expected to make, due to his position in the organization, by something over 8 per cent. It is needless to say that the amount paid the executive in bonus is quite negligible when compared to the savings effected, when reasonable intelligence is used in the application of the bonus. Staff executives, of course, whose duties do not involve either of the three adjusting factors of direct labor, indirect labor, or supplies and maintenance materials, are usually paid bonus at the base bonus rate for their particular class.

There are doubtless many other forms of incentives which can be applied to executives and those in responsible positions to accomplish the results of increased economy of operation. The three common incentives just discussed, namely, promotion, personal recognition, and bonus, are merely examples of the more prominent expedients that may be adopted to bring latent and dormant energy to the surface and convert it into company profits.

### Relation of Production Volume to Expense of Operation

It is becoming more and more the practice, especially in the automobile industry and other higher competitive manufacturing industries, to recognize the effect that ups and downs in production volume have on the expense of operation. It is of course well known that at times of curtailed output it is always advisable and sometimes necessary to retain a skeleton organization which at such times does not work at high efficiency. It is also common knowledge that as production increases, expense also increases, but at a slower rate, so that the unit expense costs at high-production are usually less than at low-production rates.

One of the methods used to show clearly the effect that variation of output has on various expense items, is to plot these expenses for past months against the production of the corresponding month. In almost every case the resulting graph shows very clearly the reduction of unit expense item costs with the increase in output of the plant. For example, the unit cost of operating the factory accounting department in one automobile plant was $24 per car when the output was 4000 cars per month; $19 per car with an output of 6000 cars; $15 per car with an output of 8000; $12 per car with an output of 10,000; $10 per car with an output of 12,000; and about $8.50 per car with an output of 14,000. Similar variations in unit expense costs are indicated for other non-productive departments, such as planning, stores, receiving, shipping, time study, machine repair, maintenance, etc. This reducing effect in the cost of overhead items with the increase in production is likewise apparent when the relation of non-productive men is considered for various rates of car production. In one plant the total non-productive men on the payroll per 1000 cars produced amounted to 425 with a monthly production of 2500 cars. When the production was 4000, the number of men per 1000 cars produced was reduced to about 300. Further increase in production to 6000 cars per month called for about 225 men per 1000 cars, and at 8000 cars production this figure was further reduced to 165 men per month.

### Stabilization of Output Throughout the Year

Not only in internal affairs, but also in those affecting vendors and distributors of product, the standardization of output plays an important factor. It might be well at this point to cite some of the means taken by a large automobile concern to stabilize output throughout the year. This is a matter of great importance to the automobile industry because of the big seasonal fluctuations in retail sales. These fluctuations are so pronounced as to be the outstanding influence on manufacturing costs. This problem is the most difficult and the most serious one the management of the automobile industry is confronted with. "Standard costs" is a term that has been honored with much consideration recently. The author will not be contradicted when he says that the greatest influence on standardization in costs is standardization of rate of output. The corporation mentioned fully appreciates the significance and importance of operating its shops on an even keel, and no production program is completely planned until the effect on costs has been estimated. This procedure has frequently resulted in a shop production rate either greater or less than the current rate of demand, especially in the production of individual parts or assemblies. They do not hesitate to increase the inventory of finished parts if by so doing a float or bank is created which at a later date obviates the necessity for operating at either peak or low demand. It might be said that the making of this decision is facilitated by the operation of a budget-control procedure that very accurately forecasts factory burden for every rate of production from minimum to maximum.

Efforts to standardize costs through standardization of rate of output should not stop with the planning of shop activities; since the fluctuation of factory output is controlled primarily by conditions in the retail field, dealer organizations may rightfully be asked to assume their equitable part in relieving the uncomfortable pressure borne by the factory during periods when the rate of output is over or under normal. The dealer naturally wishes to keep his stock of unsold products at a minimum in order to get the best turnover on his invested capital, but the dealer has a duty to the factory that sometimes necessitates carrying a stock in excess of current minimum requirements. The policy of operating a factory in strict conformity with the current retail demand not only affects the cost of output but the quality as well, and this is a matter of much concern to the dealer as well as to the manufacturer. Furthermore, if a manufacturer equips his factory for an output that will satisfy the peak demand of the dealer, he is confronted with the problem of idle machinery throughout the greater portion of the year. The only solution to this problem is to keep the rate of output from the factory as nearly uniform as possible and to take up some of this irregularity in dealer stocks.

The author would not give the impression that the company referred to is scheduling production so as to set up this uniform rate arbitrarily and then force this output upon the dealer. As a matter of fact, the rate of output does fluctuate reasonably with the field conditions. But this predetermination of ideal schedules opens the way for the factory to study retail-sales fluctuation more intelligently and to work out with the dealer a more satisfactory plan which to a large extent at least, will relieve the shop of much of the expense incident to changes from one extreme of production rate to another.

### Budgetary Control

One of the most active as well as one of the most powerful means of controlling expense is a properly designed and vigorously operated budget-control system. The comparatively recent interest in budgetary control as a specific tool of management has come about as a supplement to other developments and improvements in the science of management. Many refinements and improvements are yet to be made while it is settling into its

proper niche in the repertory of the modern industrial manager. It may be well to call attention at this point to the fact that mere installation of budgetary-control procedure will not in itself regulate expenditures. Budgetary control is simply a means to an end. It is a tool of the industrial manager's trade, and like other tools it must be designed for the work at hand in the light of past experience. It must be cared for and guided with a skilful hand if it is to serve the purpose of the master craftsman.

In the operation of budgetary-control procedure it is necessary that many contacts be made between the departments operating the budget and those in the organization responsible for actual results. Very much depends upon the nature of these contacts with respect to the results which may be expected from them. It is probably unnecessary to say that the relation of those operating the budget to those responsible for obtaining results in the factory should be that of the counselor, the guide, the helpful team mate. Dictatorial policies of the budget-control department are usually met with resentment, ridicule, and finally with contemptuous disregard. Cooperation can be realized best when those responsible for expenditures are allowed a voice in the determination of their budgets. Such cooperation usually results in budget quotas that are at once sufficiently reasonable to command respect and encourage thrift, and at the same time sufficiently rigid to stimulate vigilance on the part of the executive and prompt him to challenge every item of outlay with the words, "is this absolutely necessary?"

Like all attempts to discount the course of future trends, budgetary-control procedure and budget quotas should be based upon the experience of the past. Undoubtedly it should be the more immediate past, in order to avoid the mistakes which would undoubtedly occur in judgments based upon data compiled when manufacturing conditions were different.

As just mentioned, the mere setting of budget quotas does not in any way replace the necessity for strict, intelligent, and vigorous enforcement of means for the realization of these quotas in so far as is practically possible. Usually the type of man at the head of a department who would be called upon to submit proposed budget figures for his department would also be one from whom intelligent judgment on such matters might be rightfully expected. Furthermore, he is in a position to know the detail of the operation of his department, and therefore understands reasons which may not be apparent to the budget department for deviations from results which might seem in all fairness to be rightfully expected. It is the placing of attainable budget quotas before executives as guides in the operation of their departments and as measuring sticks for results which they are expected to accomplish that constitutes one of the biggest steps toward enforcement and accomplishment of budget quotas.

The next move is to provide the department head with sufficient detail data to enable him to actively and intensively study the situation in his department with the idea of enforcing the desired results upon his subordinates. Accurate reports and information showing the relation between actual accomplishments and budget quotas are essential in this respect. He must know how near he is coming to the mark in order to correct his aim the next time.

### Methods of Carrying Out Budget Procedure

At this point it might be well to describe briefly the methods used by The Chrysler Corporation in carrying out its budget procedure. This corporation was one of the earlier large establishments to adopt the budgetary-control method of operation. Of necessity its beginnings were crude, but as time has passed many refinements have been made in methods as well as in requirements imposed upon the budget scheme. Much that was thought necessary in the beginning has been cast aside as of doubtful value. Some other features not thought vital in the earlier days have later been developed and found extremely useful.

It is very natural for a department head, who is to be held responsible for results which he says he can accomplish, to make his estimates sufficiently high to enable him to avoid possible embarrassment if he should fail to meet his estimate. Furthermore, there is a tendency to set forth all kinds of excuses and alibis for not attaining his budget, claiming that he was not informed or that he had no responsibility in that direction, or that he was not consulted as to what the quota ought to be. When a department head is allowed a voice in setting his own quota reasonably close and is expected to attain that quota, he is much more likely to give the affairs of his department the close scrutiny which the preparation of an intelligent budget quota requires. It was found from the outset that it was necessary to establish some fairly well-defined standards of operation for the various departments in order that the accuracy of the department head's estimate could be measured intelligently. The first step in this direction is an exhaustive analysis of past performances. Statistics are compiled showing the relation between the volume of business and the volume of department outlays, and these figures are used as a basis for computation of a master budget, in which is set up for each department a standard expense per unit for production varying from the minimum to the possible maximum. The purpose of establishing these units of expense for each department is to act as a general guide in the preparation of budgets and as a basis for criticism when such budgets submitted were too far out of line. The master budget which resulted from this procedure was the management's idea of what a reasonably creditable performance should be. The aim was to make quotas such that they could be realized with good judgment and careful management without too great a difficulty, and to always have them backed up by similar performance in the past. When the department head understood that excessive budget requests above results which had already been attained required an explanation from him he was quite likely to give extreme care to the estimates which he prepared.

When final results for the month were available, they were compared with the quotas established, and any deviations which reacted unfavorably to the department were accounted for. The outcome of these explanations is usually a better understanding of the difficulties and requirements of the departments, and is usually reflected in more carefully set budget quotas for the ensuing months. In this way unnecessary expenditure is brought to light, and department heads are constantly kept alive to the necessity of reducing all avoidable losses to a minimum. By the continual process of forcing intimate investigation and analysis of the operation of his department, the department head is educated into the essentiality of expense reduction and prudent authorization of department expenditures.

While it is undoubtedly true that many businesses have prospered greatly which have never heard of "budgetary control," nevertheless, it is exceedingly doubtful that these concerns do not practice many of the principles laid down as fundamental to the operation of a budgetary-control feature. It is very likely that much of their success, much of their ability to reduce expenditures, to cut corners, to produce in the best, quickest, and easiest way, is directly traceable to principles which we are now talking and reading about under the name of "Budgetary Control."

## Discussion

F. Klein.[2] The writer's company has just completed a budgetary control of work expenses. While installing the system, we asked a foundry foreman to account for all of his indirect labor. We found he had incurred a number of charges of which he knew nothing. He was surprised to find that some men in the yard gang had been charging a whole day's time for about an hour when he had been using them. As a result of checking up on their time, the yard men soon had no place against which to charge their time, and a reduction of force was brought about.

Shortly after the budget was completed, a foreman had two carpenters come into a department to repair some flooring. The job was done in about one hour. The following week, the foreman was surprised to find that the maintenance account was considerably in excess of his allowance. Upon inquiry, he learned that the carpenters had charged six hours apiece for the job. He took the matter up with the maintenance superintendent and found that we had too many carpenters, who were simply inflating each account to take care of their idle time.

The foregoing are just little instances which occur in the installation of a budgetary control, and show that foremen do not know just what goes into the various accounts of indirect labor and other indirect items. As we go along with the regular weekly reports, we find other small leaks which will be eventually stopped through the continual control afforded with the budgetary expense control.

In setting up the control figure for each department, we first determine the 100 per cent operating capacity for that department. The number of different machines, or benches, or the other available space for productive labor is multiplied by the number of working hours in the week. The product is the 100 per cent capacity in working hours. A comparison with the number of productive hours which are actually being worked, gives the ratio of the present to the 100 per cent operating capacity. We then take up with the head of the department the requirement of indirect labor under his 100 per cent operating capacity, and step up the percentage of indirect labor to a possible 120 per cent or down to a possible 40 or 50 per cent, if those percentages are considered the maximum and minimum of the range of operations, and vary the indirect labor allowance according to the actual requirements under the various capacities. We also increase and decrease the supplies that are used in the products themselves, but proportionately. Those supplies which are used ordinarily in the maintenance of the department, supplies for cleaning, and those of a nature which do not increase or decrease proportionately, are set on a different basis.

[2] Worthington Pump & Machinery Corp., New York.

When the total cost of operation under different operating capacities is determined, it is entered on a chart which agrees with the set-up of the regular monthly report of indirect expenses. The top of the form shows the number of productive hours worked under each operating capacity. Under that is the percentage of operating capacity, and under that is the amount of money allowed for the different kinds of operating expenses. Thus when orders drop to a thousand from possibly 1500, we may call for a reduction of certain indirect men at that point. The tendency always is to keep indirect men in the shop in the hope that production will soon come back to normal, but when the budget shows that a reduction is in order but that it is not made, the foreman is required to account for his excess help, if the reduction is not made during the following week.

C. W. Spicer.[3] In our company we have carried budgeting and assignment of duties into the experimental laboratories and drafting room. No work is performed in those departments without an express order, approved by the proper executive. We have found that not so many drawings are asked for as formerly. In the experimental laboratories the work is budgeted so that only the necessary work is being done, and there are not so many individuals seeking information on particular details which may not directly relate to the work of the company.

G. R. Ingels.[4] The author states that the higher executive's premium or bonus should be based on the earnings of the company. The writer believes otherwise. Take any executive's position and list his duties. If he is on the production side, he has to do with the kind of material used and the amount of material used as limited by scrap factors and by labor. But in the total cost of an item being produced by most companies, the labor on it will seldom be more than 12 per cent. The cost of raw material is the big item. Most executives have relatively little to do with the cost of raw material—the biggest single item going into the cost of manufacture of a product.

Another item is the selling cost. Few executives have much to do with the earnings of the company. They have to do particularly with some one or two items rather than with a dozen items entering into cost. Should not those items be the ones to affect a man's premium to get him more interested, and should not the other items affect the other man's bonus likewise, rather than the earnings of the company? Prices may be set outside of the company, and the company may not have any earnings, yet there may be some man there doing wonderful work and deserving of a premium.

[3] Spicer Mfg. Corp., South Plainfield, N. J. Mem. A.S.M.E.

[4] The Charles E. Bedaux Co., Chicago, Ill. Assoc-Mem. A.S.M.E.

# Economic Production Quantities

## Derivation of Formulas for Determining Quantity Which Can Be Produced at Lowest Total Unit Cost, Taking into Account Fixed Charges, Investment Charges on Capital, Rental Charges, and Losses Due to Deterioration, Obsolescence, and Nature of Process

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INDUSTRIAL executives and production managers are requiring more exact methods to enable them to control investment in inventories and to regulate production schedules so as to conform more closely with the variation of the business cycle, and to accomplish this with the most liquid condition of working capital. In most cases the greatest effort has been applied to reducing the unit cost of the product to the lowest possible in order to realize a satisfactory margin of profit under the conditions of aggressive competition evident today. Scientific methods of management have been developed in order to obtain all possible elimination of waste in time, labor, and material. However, no exact method has been established for determining the best quantity to be processed at any one time. The Economic Production Quantity is that quantity which can be produced at the lowest total unit cost, taking into consideration not only fixed charges on each process order, and investment charges on the capital involved, but also rental charges on the space occupied by the article when carried in stock, and losses due to deterioration and obsolescence and the nature of the process.

### Applications of the Economic Production Quantity

The law of the Economic Production Quantity provides a new and reliable means for directing and controlling the output of any industry by coordinating manufacturing and marketing conditions. Definite production schedules and sales policies can be properly established so as to anticipate the seasonal as well as the major swings of the business cycle. The planning department can be provided with actual facts expressed in the simplest form and based on the conditions of the manufacturing process involved, and schedules of work in process need no longer be maintained on estimates of an uncertain origin, generalizations, and the demands of insistent customers. Management can maintain a greater control of working capital, only tying up such amounts as the actual market conditions warrant, thereby maintaining inventories in the most liquid condition. Purchases can also be controlled by the formula for economic production quantities by the proper substitution of terms in the general equation, thereby correlating the receipt of raw material with the demands of the production schedules and eliminating unnecessary charges on capital tied up in such inventories.[2]

Moreover the type of process best suited to the manufacture of a given article, together with the probable machine capacity required, may be determined by this law. In general, processes can be classified according to the rate that production may proceed in order to balance consumption, and for further discussion will be considered as being either continuous, semi-continuous, non-continuous, or batch production. The last class modifies the third so as to realize the advantages of the first two which could not otherwise be accomplished. By means of a simple investigation of market conditions and an analysis of the sales demand the most seriously indeterminate factor of consumption can be reduced to a reliable and practical basis.

Although the ideal formula is complicated in appearance, it expresses the true relation of the fundamental facts, indicating the influence of each of these facts on the others, and establishes the economic law in a mathematical form. Mechanical means of solution such as slide rules, graphs and nomographic charts, can be developed, especially when the particular type of industry is known, which will shorten the time of calculating the economic production or purchase quantities.

### Mathematical Expressions

The law of the economic production quantity can be expressed mathematically in two forms, one exact and one approximate, and may be written as follows, showing the respective relation of the fundamental components:

$$Q = \frac{-F \times k'_s}{I''_s + I''_w + V''} + \sqrt{\left[\frac{F \times k'_s}{I''_s + I''_w + V''}\right]^2 + \frac{FPY''}{I'_s + I'_w + V'}} \quad \text{(Exact form)}$$

and

$$Q = \sqrt{\frac{F\,P\,Y'''}{I'_s + I'_w + V'}} \quad \text{(Approximate form)}$$

where

$Q$ = economic production quantity (pieces)
$F$ = fixed or preparation costs (dollars)
$P$ = rate of production (pieces per day)
$Y''$ & $Y'''$ = expressions representing the sales or demand (pieces per day)
$I'_s$ & $I''_s$ = expressions derived from $I_s$ representing the investment charge on inventories (dollars)
$I'_w$ & $I''_w$ = expressions derived from $I_w$ representing the investment charge on work in process (dollars)
$V'$ & $V''$ = expressions derived from $V$ representing the rental charge on the storage space (dollars)
$k'_s$ = coefficient representing the conditions involved in withdrawal of finished articles from stock to meet the sales demand.

It will be shown in the derivation of these various expressions that the other fundamental factors, such as variable sales demand, deterioration, and obsolescence are included in these final components as well as those factors which apply to the nature of the process or type of industry. These formulas for the Economic Production Quantity $Q$ are derived by differentiating the total unit cost $U$ with regard to $Q$ and equating the result to zero, as $Q$ must be by definition that quantity which is produced at a minimum unit cost. The total unit cost $U$ is composed of the direct production cost $c'$ of material, labor, and overhead, and the unit allotment of the preparation cost $F/Q$, the investment charges on inventory $I_s/Q$, and on work in process $I_w/Q$.

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[1] Crosby Steam Gage & Valve Co., Assoc-Mem. A.S.M.E.

[2] The particular application of the law of the economic quantity to purchasing has been ably discussed by R. C. Davis in *Manufacturing Industries*, May, 1927.

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the rental charge for the storage space $V/Q$, and the loss involved by deterioration of articles in stock $D/Q$. This can be written mathematically as

$$U = c' + \frac{F}{Q} + \frac{I_s}{Q} + \frac{I_w}{Q} + \frac{V}{Q} + \frac{D}{Q}.$$

The exact solution requires that the cost of the finished article held in stock when applied to the expressions $I_s$ and $D$ be the total unit cost $U$, whereas the approximate solution assumes that the cost of the finished article in these two expressions is only the manufactured cost of such article when received in stock which amounts to $c' + (F/Q)$. In most cases when the law of the Economic Production Quantity is actually applied to a problem in an industry the approximate formula is used as it is sufficiently accurate and the time and labor saved in employing the shorter form far outweighs the slight increase in accuracy of the results if calculated from the exact formula. The error in the results between the two formulas is negligible in the long run, except when $Q$ is very small, as the natural error in estimating an average or representative demand figure $Y$ will wholly counteract this discrepancy.[3]

The theoretical formula for the Economic Production Quantity in the approximate form and including all contributory factors and coefficients may be written as follows:

$$Q = \sqrt{\frac{FP\{2\theta Y_a - \Delta[\theta Y_a + Y'_r(f-1)i]\}}{c'i\left[(k+f-1)\Delta P - \theta Y_a\left(\frac{1-\frac{1}{n}}{2}\right)\right] + c'i.\theta Y_a\frac{k_pi}{a'} + vB\Delta\left[Pf - Y_a\left(1-\frac{1}{n}\right)\right]}} \quad \ldots\ldots[1]$$

(Approximate solution)

Even such an equation, at first thought, is open to criticism on the ground that it is purely theoretical and too complicated for the average industry, and will require too much energy and time to solve when it must be applied to a large variety of lines and a correspondingly larger number of component parts. However, upon further investigation considerable simplification is possible when applied to a given type of industry, as the various items may be divided into groups, several of which are general in their application and will reduce the formula to one having but a few special items. All terms may be arranged in four groups according to the influence of

- *a* Production or consumption rates
- *b* General economic values
- *c* The specific process
- *d* The individual part.

The resulting special formulas will be comparable to such similar ones as have been developed for a specific industry without regard to the problem as a whole. Accordingly with the application of mechanical means of solution as previously suggested the universal use of the law of Economic Production Quantity is quite practical.

### Types of Industrial Processes

In applying the law of the Economic Production Quantity to actual conditions it becomes necessary to divide industries as a whole into four types depending upon the nature of the processes involved. To the first type belong those industries which are fortunate in being able to obtain the ideal manufacturing conditions and can arrange groups of machinery or processes which will produce continuously, thereby eliminating set-up costs and bringing supervision and maintenance costs to a minimum. By a proper balancing of the units of production a steady flow can be maintained to follow closely the sales demand, and the stock held of finished articles need only be sufficient to take care of an emergency. In the case where the demand fluctuates due to seasonal variations it may be necessary to maintain additional articles in stock in excess of the reserve stock to smooth out irregularities in the demand, and this will require a larger inventory. Either of these conditions, however, is preferable, in the light of final costs, to intermittent periods of production.

To the second type of industry belong those having a more varied line of products and a diversified sales demand and to which continuous production cannot be applied in full as the number of units produced would exceed the sales. It may, however, be applied in part, production then proceeding at a semi-continuous rate. The nature of the process is such that the articles can be manufactured at a continuous rate for a stated period and withdrawals from work in process can be made to meet the consumption during that period, the remainder of the work in process being then placed in stock to supply future demands. Provision must be made for a larger stock to be carried than in the first case, which naturally increases the investment in inventory. The production periods for the same article are repeated at intervals; meanwhile the machine equipment is shifted to the production of other articles of a related nature, and will be again used to produce the original article when the quantity in stock has reached the order point.

The third type of industry can in no way take advantage of continuous production, and therefore no material can be withdrawn from work in process to meet sales until the whole number of articles being processed is entirely completed. The inventory problem now becomes more complex as the entire number of finished articles must be placed in stock before they are available for consumption, and a definite order point with its minimum stock must be maintained, as well as a reserve stock to be used in case of emergency. However, if the various operations composing the process can overlap, groups of articles can be processed in such a manner that as soon as the first group or batch comes off the last operation it can be withdrawn from work in process and placed in stock, thereupon being available to meet consumption. By this means the industries in this class can approximate the condition of industries of the second type, and will be considered as operating on the principle of batch production. As in the second case, the machine equipment is shifted from one process lot to another, each lot being composed of similarly related articles, until it is time again to replenish the stock of the original article.

A fourth type of industry is represented by the job shops where all articles are produced in small or unrelated quantities at irregular intervals or are never to be produced again. The preparation and supervision costs amount to a large proportion of the unit cost, and no stock is kept in stores as the completed lot is immediately shipped to the customer who assumes the storage responsibility.

### Analysis of Factors

Following out this grouping of the various types of industry, an analysis can be made of the theoretical formula [1], which will demonstrate the influence of each term on the result and establish the limits within which such terms may be varied by specific conditions. For example:

[3] The practical limits of use for the approximate solution are excellently discussed in an article by George Pennington, published in *Manufacturing Industries*, March, 1927.

*a* If the production rate $P$ is omitted from the formula, no allowance has been made for the effect of the manufacturing period on stores, or the expression for $Q$ is being used to control purchases.

*b* If the consumption rate $Y$ appears to be zero, no definite sales demand exists, individual orders are received for stated quantities, and shipments are made as specified. No application of the principle of economic production quantities can be made under these circumstances, as the industry is a jobbing shop of the fourth type.

*c* If the stock coefficient $k$ is zero, no stock is held to offset the sales, as the conditions are the same as above. If $k$ equals one-half, the consumption is uniform; if $k$ is less than one, but not equal to one-half, the consumption rate is variable; and if $k$ equals one, there is no consumption, and the industry is performing a storage function, such as a warehouse, and maintains the articles in stores for a definite period of time.

*d* If the reserve stock factor $f$ is zero, the industry is operating on continuous production, if $f$ is less than one, a small minimum stock is held—insufficient, however, to cover the consumption during the manufacturing period up to the first delivery to stores from work in process; if $f$ equals one the full requirement for the minimum stock exists, affording complete protection during the manufacturing period; and if $f$ is greater than one, a reserve stock is also maintained to meet emergencies.

*e* If the preparation cost $F$ is zero, the industry is operating upon continuous production, and if it has a finite value the industry is operating upon the principle of economic production quantities.

*f* If the production cost $c'$, including material and labor, is zero, the industry is performing a service and is not producing a finished product; but if $c'$ equals $m$ (the material cost), all the labor is applied to preparing the process which takes care of itself when production begins. This condition would exist in a chemical industry, where no direct labor is added to change the condition of each unit, and where the labor cost is independent of the units produced.

*g* If the batch factor $n$ is zero there is no production, and the formula for $Q$ is used to control purchases, except where partial shipments of raw material are made over a period upon a single purchase order. If $n$ equals one, all articles are produced in one lot and delivered to stores at the end of the manufacturing period; if $n$ is greater than one the production is intermittent, and each lot is divided into batches; if $n$ is infinite the production is continuous.

*h* If the operation factor $a'$ is less than one, the various operations overlap and all lots are divided into batches; but if $a'$ equals one, the special case exists where all operations follow in sequence, $t_1$ equals $t'$, and if they are considered as one operation, $t_1$ equals $t'$ equals $T_p$.

*i* If the coefficient of obsolescence $\theta$ equals unity no allowance is made for this condition; if $\theta$ is less than one the quantity manufactured will be insufficient to meet the current demand, showing that the factor has been wrongly determined; if $\theta$ is greater than one, the fractional part of the remaining demand has been properly distributed to meet the full requirements up to the time of obsolescence.

*j* If the coefficient of deterioration $\Delta$ equals unity, no allowance is made for this condition; if $\Delta$ is less than one, deterioration is properly accounted for.

### Existing Formulas

Simple expressions for the Economic Production Quantity have been developed from time to time to meet the requirements of a specific industry, but no one of them includes all the factors which govern the problem, so that none of these can be used as a general formula embracing all conditions that could possibly arise. The most common forms that exist are:

$$Q = \sqrt{\frac{2FY_y}{c'i_s}} \text{ (Approximate form)}$$

and

$$Q = -\frac{F}{c'} + \sqrt{\left(\frac{F}{c'}\right)^2 + \frac{2FY_y}{c'i_s}} \text{ (Exact form)}$$

where $Q$ = the Economic Production Quantity (pieces)
$F$ = preparation costs (dollars)
$Y_y$ = demand (pieces per year)
$c'$ = direct cost, including labor, material, and overhead (dollars per piece)
$i_s$ = the investment-rate charge composed of an interest rate, the storage charge distribution rate and a rate representing the unit allotment of taxes, insurance and general expenses (per cent).

The most common variations appear in the terms $Y$ and $i_s$, as the period of time may be expressed in terms of days, weeks, months, or years, with appropriate corrective factors. It also has been the practice to express the number of pieces in units of thousands.

### Determination of the Ultimate Unit Cost

The actual determination of the ultimate total unit cost of any part or article or class of product depends upon two fundamental factors. The first, representing the direct cost of material and labor, with an overhead allowance, is common to all cases and is specifically governed by the laws of scientific management. The second, representing the investment charges on capital involved in work in process and in inventory, and the rental and maintenance charge on manufacturing and storage space, which increase in importance as the production methods become less flexible and more unlike the ideal conditions of continuous production, has been a study for financial experts and accountants. In order to balance inventories with sales demand and control inventory values, which should not exceed the accepted relation of approximately 25 per cent of the total capital worth, these factors must be expressed and combined in a relation representing the total unit cost of any product which can be solved for its Economic Production Quantity.

### Manufacturing Cost

The production cost of an article $c'$ is composed of the unit material cost $m$, plus the unit labor cost $l$, plus the unit allotment of overhead on operating time $o$, and can be expressed by

$$c' = m + l + o$$

or

$$= m + \Sigma h(d_l + d_o)$$

if the labor and overhead items are reduced to terms of the sum of all the production time per piece $h$, the hourly labor rates $d_l$, and the burden rates $d_o$ of each department involved.

The preparation cost $F$ is a fixed charge against the whole order irrespective of the number of parts produced upon the order, and is composed of various factors which include the expense of specification writing and drafting-room work ($D$) peculiar to each order, planning and scheduling of the order ($G$), issuing of the order ($O$), tool preparation ($T$) including special, tools, and machine set-up ($S$). It cannot be reduced to a unit value independent of the quantity $Q$ and therefore must be expressed by

$$\frac{F}{Q} = \frac{D + G + O + T + S}{Q}$$

The manufacturing cost $c$ includes the cost of production with that of preparation, and when reduced to a unit cost may be expressed by

$$c = c' + \frac{F}{Q}$$

This equation is not a straight-line function and approaches certain asymptotes as limits (Fig. 1) when plotted with quantities of production as abcissas.

### Investment Charge on Inventory

The investment charge $I_s$ on capital involved in inventories is quite a complex factor as it depends upon the average quantity in stock $S_a$ for a given sales period $T_s$, and is the result of balancing the demand with a reasonable production schedule, to which is applied an interest rate $i$ also composed of several factors, together with either the total unit cost $U$ or the simple manufacturing cost $c$, depending on whether an exact or approximate solution is desired. Accordingly the expressions for the investment charge on inventory can be written (see Fig. 2).

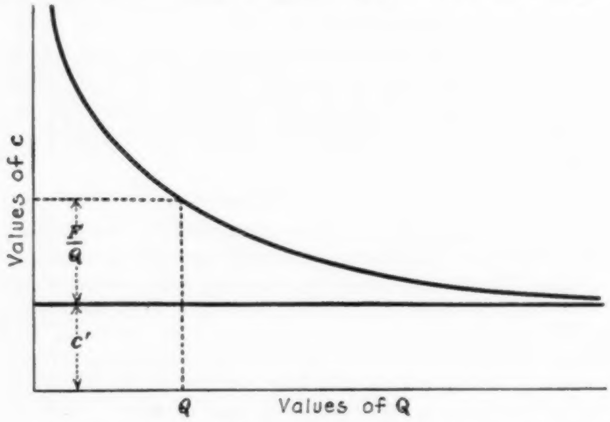


Fig. 1 Manufacturing Cost ($c$)

$$I_s = S_a \times c \times i \times T_s \qquad \text{(Approximate form)}$$

or

$$= S_a \times U \times i \times T_s \qquad \text{(Exact form)}$$

These expressions are straight-line functions of the production quantity $Q$ and the cost $c$ or $U$ in terms of dollars, and, when plotted with $Q$ as abscissa and $c$ or $U$ as ordinate, show that the investment charge increases steadily as the quantity of production increases.

### Length of Sales Period

Before the expressions for the average stock can be derived it will be necessary to consider the terms representing the sales demand and the length of the sales period. Sales records of previous years when referred to will give ample data for determining the necessary figures for the consumption rate; however, as this is usually expressed in terms of pieces per year $Y'_y$, it should be reduced to a common factor of pieces per day $Y'_d$ as an average for the year. This method takes no account of seasonal fluctuations or the general trend of the industry which will of necessity be considered later on, and for the present only an average demand $Y_a$, in terms of pieces per day, will be used. The duration of the sales period $T_s$ expressed in days is not an independent variable as it is controlled by its relation to that quantity $Q$ chosen as the most desirable to manufacture in order to meet the consumption during this particular unit of time, and cannot be reduced to an exact value until the actual value of the production quantity $Q$ is economically determined. From the foregoing discussion the following expression may be derived:

$$Q = Y_a T_s$$

for the quantity $Q$ was produced to meet the demand $Y_a \times T_s$ and must be exhausted when the period $T_s$ is at an end.

Hence

$$T_s = \frac{Q}{Y}$$

### Average Stock

The form of the expression for the average stock $S_a$ depends upon the type of industry in question. In the case of the first type operating at continuous production,

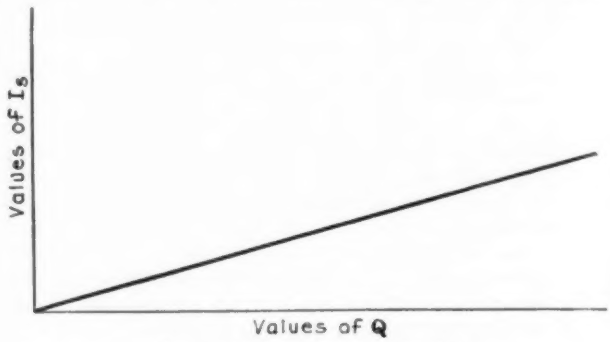


Fig. 2 Investment Charge ($I_s$)

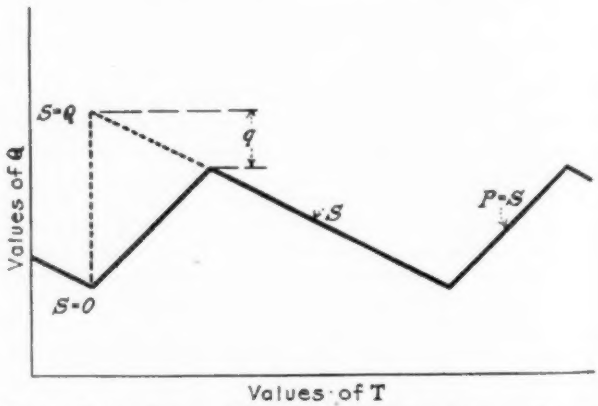


Fig. 3 Stock Curve: Semi-Continuous Production, Uniform Demand—Case II

$$S_a = 0$$

as there are no periods without production during which stock need be maintained to meet sales. In the case of the second type of industry, where continuous production proceeds at stated intervals, there is a time when articles are withdrawn directly from work in process for which it is necessary to make an allowance. The final quantity in stock at the end of the production period is equal to the production quantity $Q$ less the number of articles withdrawn during that period, which can be expressed by

$$q = Y_a \times T_p$$

where

$$T_p = \frac{Q}{P}$$

and represents the time required to complete production. The expression for the average stock then becomes

$$S_a = \frac{Q - q}{2} \qquad \text{(Fig. 3)}$$

$$= Y_a\left(kT_s - \frac{T_p}{2}\right)$$

$$= Q\left(\frac{kP - Y_a \times {}^1/_2}{P}\right)$$

where $k$ = the coefficient $^1/_2$ applied to articles in stock.

The effect of the allowance for the manufacturing period is to reduce the investment charge, but this advantage can be realized only if production can proceed continuously throughout the manufacturing period (Figs. 4 and 5). In the case of the third type of industry where there is no possibility of withdrawing articles from work in process, as all articles are manufactured

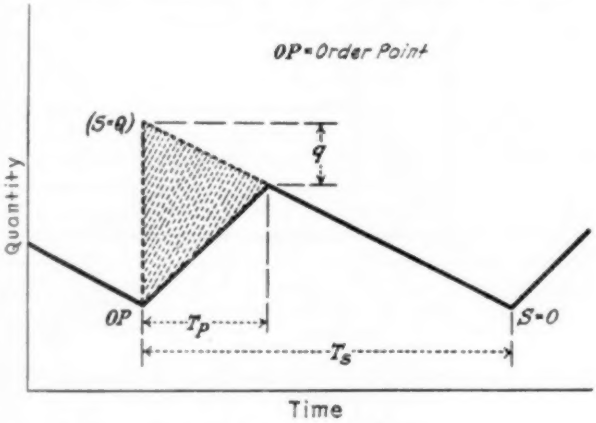


FIG. 4 SAVING BY SEMI-CONTINUOUS PRODUCTION OVER NON-CONTINUOUS PRODUCTION, UNIFORM DEMAND—CASE II

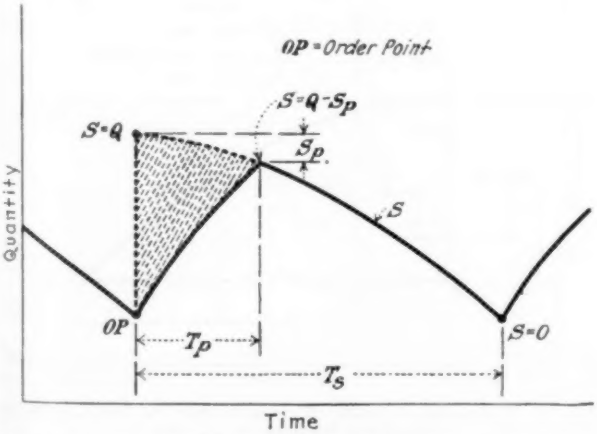


FIG. 5 SAVING BY SEMI-CONTINUOUS PRODUCTION OVER NON-CONTINUOUS PRODUCTION, VARIABLE DEMAND—CASE II

before the sales period begins, the expression for the average stock becomes simply

$$S_a = \frac{Y_a \times T_s}{2}$$

$$= Q \times k. \qquad \text{(Fig. 6)}$$

However, as indicated previously, if it is possible to apply the principle of batch production to an industry of the third type a considerable saving in investment charges in inventory can be made. This can be accomplished if the production lot be subdivided evenly into a number of batches. The size of each batch is determined by the number of pieces which can be carried in a group from one operation to another, so that each operation overlaps the other, reducing the total production time once it has been set up, and can be continuously maintained. Accordingly, once production has begun at a rate $P$, batches will be completed at uniform intervals, and thereupon will be available to meet withdrawals from stock. In other words the principle of batch production approximates the principle of continuous

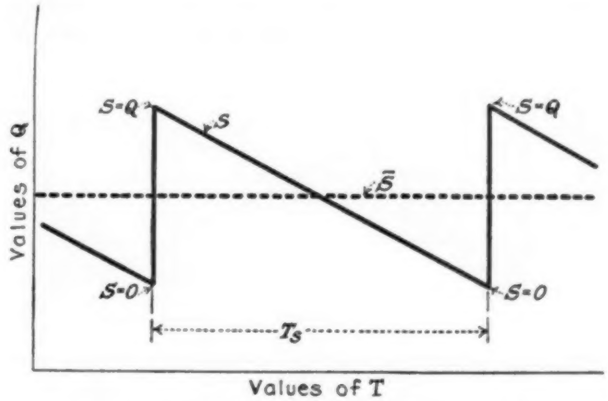


FIG. 6 STOCK CURVE: NON-CONTINUOUS PRODUCTION, UNIFORM DEMAND—CASE III$_a$

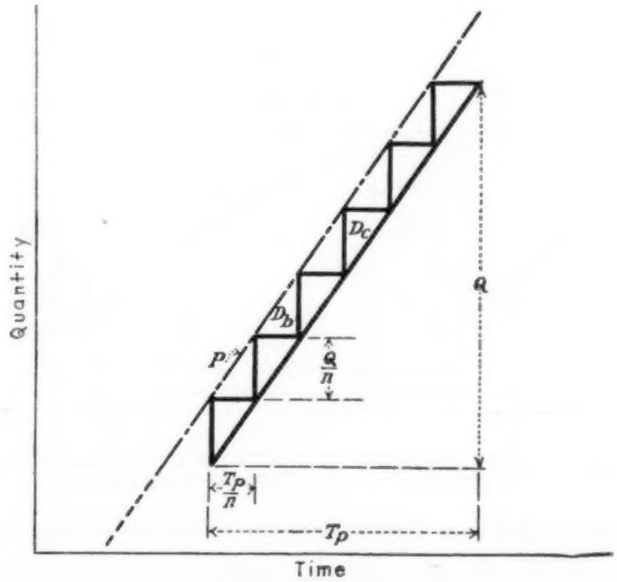


FIG. 7 DELIVERIES TO STOCK FROM WORK IN PROCESS—CASE III$_b$
($D_b$ = batch production; $D_c$ = continuous production.)

production (see Fig. 7), and if an infinite number of batches are arranged it becomes continuous production. Batch production has the advantage of reducing: first, the time required between the order point and the withdrawal of all stock; second, the minimum stock required; third, the average stock in stores during the remaining part of the production period, where it overlaps the sales period; and most important, the total investment charge. The resulting effect on the stock is shown by Figs. 8 and 9.

The method of evaluating the average stock is quite evident

from inspection of the conditions as illustrated in Figs. 10 and 11, and can be written

$$S_s = \frac{A_1 - A_2}{T_s}$$

where $A_1 = QkT_s$ and

$$A_2 = QT_p\left(\frac{1-\frac{1}{n}}{2}\right)$$

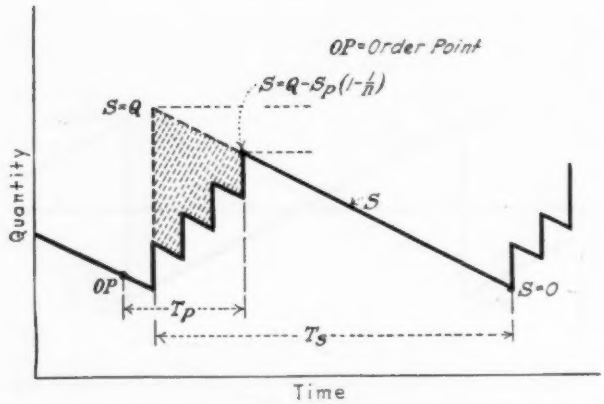


FIG. 8 SAVING BY BATCH PRODUCTION OVER NON-CONTINUOUS PRODUCTION, UNIFORM DEMAND—CASE $III_b$

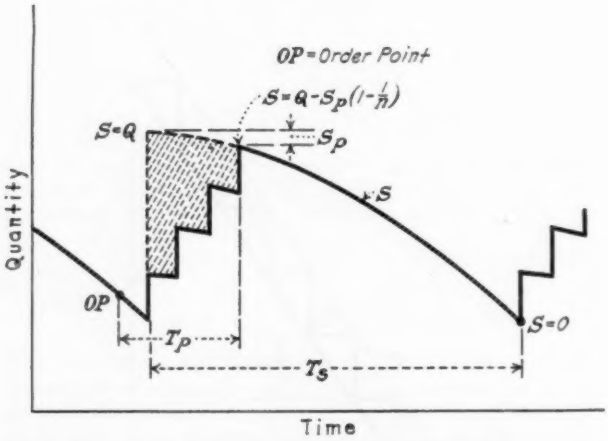


FIG. 9 SAVING BY BATCH PRODUCTION OVER NON-CONTINUOUS PRODUCTION, VARIABLE DEMAND—CASE $III_b$

Substituting these terms in the above equation and reducing,

$$S_s = \frac{Q}{T_s}\left[kT_s - T_p\frac{\left(1-\frac{1}{n}\right)}{2}\right]$$

$$= Qk_s, \text{ where } k_s = \frac{kT_s - \frac{T_p}{2}\left(1-\frac{1}{n}\right)}{T_s}$$

Again for industries of the fourth type the value $S_s$ of the average stock is zero as the storage obligation does not exist.

A general expression for the average stock may be written with a new coefficient $k_s$ which will represent the condition of the inventory in any kind of industry; hence if

$$k_s = \left(kP - Y_s\frac{\left(1-\frac{1}{n}\right)}{2}\right)\frac{1}{P}$$

$$S_s = Qk_s$$

### Reserve Stock

In certain types of industry where an unforeseen change in the demand might arise, it is advisable to maintain a reserve stock in excess of the stock required to meet the expected consumption, and this phase of the problem has been discussed by R. C. Davis in *Management and Administration*, April, 1925, wherein a formula was developed which included this item. In deriving the expression for the average number of articles in

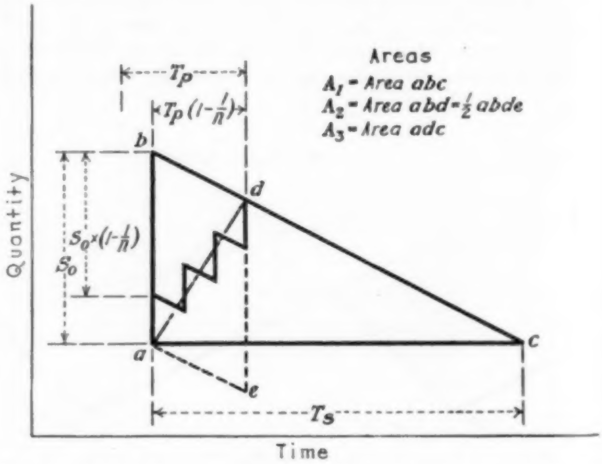


FIG. 10 BATCH PRODUCTION: DETERMINATION OF AVERAGE STOCK, UNIFORM DEMAND—CASE $III_b$

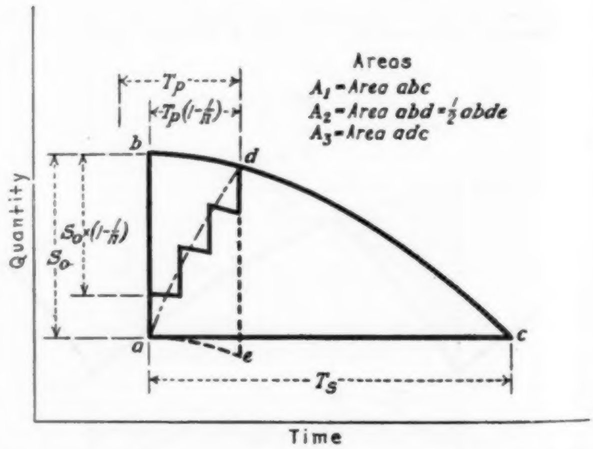


FIG. 11 BATCH PRODUCTION: DETERMINATION OF AVERAGE STOCK, VARIABLE DEMAND—CASE $III_b$

stock throughout the turnover period, the total reserve stock $S'_r$ is taken as including the stock on hand at the order point, or the minimum stock held to offset consumption $S_m$ during the manufacturing period, and the special reserve stock for emergencies $S_r$. The relation of these items is illustrated in Fig. 12, and can be rewritten in a form similar to those used in this paper:

$$S'_r = S_m + S_r \quad \text{and} \quad S_r = S'_r - S_m$$

As $S_r$ and $S'_r$ are arbitrary quantities they can be expressed in

terms of the definite quantity $S_m$ by applying a coefficient $f$, and then the relations become

$$S'_r = S_m f$$

$$S_r = S_m(f-1)$$

As long as the minimum stock does not exceed the total reserve stock the coefficient $f$ is greater than one, and the term $(f-1)$ is positive, showing that there is a quantity remaining indefinitely in stores to meet emergencies. However, if for some reason a change in the demand has caused an excessive withdrawal of articles from stock, the total reserve stock may be reduced so that $S'_r$ becomes less than $S_m$ and then the coefficient $f$ is less than one, and the term $(f-1)$ becomes negative. This shows that the minimum stock allowance will not last through the normal production period, and that production on a new lot must be commenced at an earlier date, due to the fact that the order point has been advanced by the withdrawal of an extra quantity which would otherwise have met the consumption up to the end of the turnover period $T_s$. It is doubtful whether any actual application of the negative value of the term $(f-1)$ would arise, as all calculations for the economic production quantity are made from known conditions and the negative value would only appear from some sudden and unexpected change in the demand. If such a change can be foreseen it can be accounted for naturally in the original estimate for the average daily demand rate $Y_a$ for the consumption period by the method of forecasting, as will be outlined later under the topic of variable demand. To complete the derivation of the terms $S'_r$ and $S_r$ it is necessary to obtain the quantity $S_m$ in stock at the order point, or that quantity which is required to meet consumption during the initial periods of production before withdrawals can be made from work in process.

$$S_m = Q - Y_a T_r$$

$$= Q - Y'$$

where $T_r = T_s - T_m$ and $T_m$ is the time required, in advance of the end of the period $T_s$, for the production of a new lot or batch.

Then
$$S'_r = f(Q - Y'_r)$$

$$S_r = (f-1)(Q - Y'_r)$$

From this the expression for $S_a$ can be obtained by the same procedure that was employed above, but where

$$S_a = \frac{A_1 - A_2 + A_3}{T_s} \quad \text{(Fig. 13)}$$

and
$$(A_1 - A_2) = Qk_s T_s$$

$$A_3 = (Q - Y'_r)(f-1)T_s$$

Then
$$S_a = Q(k_s + f - 1) - Y'_r(f-1)$$

Should the conditions for variable demand exist the value of $S_m$ can be derived from the general expression of the stock curve as given later, as follows:

$$S_m = Q - \int_0^{T_r} Y\,dT$$

### Interest Rate

The interest rate $i$ charged against capital invested in inventories represents that rate of return expected from working capital which is actively employed, and may amount to as much as 20 or 25 per cent a year, which should then be reduced to terms of days.

### Investment Charge on Work in Process

In practically all previous determinations of the Economic Production Quantity no consideration has been given to the investment charge upon work in process. During production, labor, with its accompanying overhead charge, and material are being so combined that at any given time there is a definite amount of capital $C_w$ invested in work in process, depending upon the degree of completion that has been attained up to that instant. Accordingly, the investment charge upon this capital can be expressed generally by

$$I_w = C_w i_w T_w$$

where $i_w$ equals the interest charge on the capital and $T_w$ equals the time over which the capital is employed in work in process. At continuous production the value of $C_w$ is a constant and

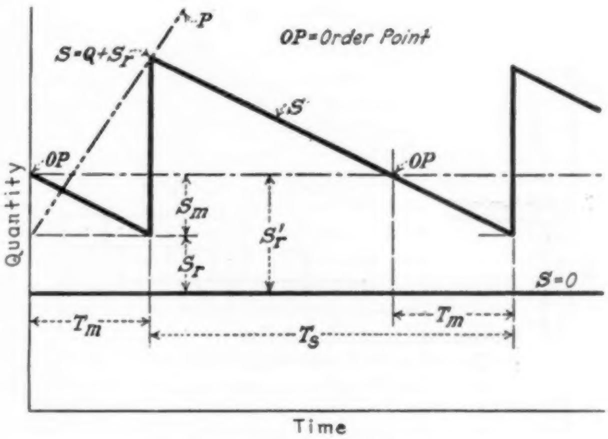


Fig. 12 Effect of Reserve Stock

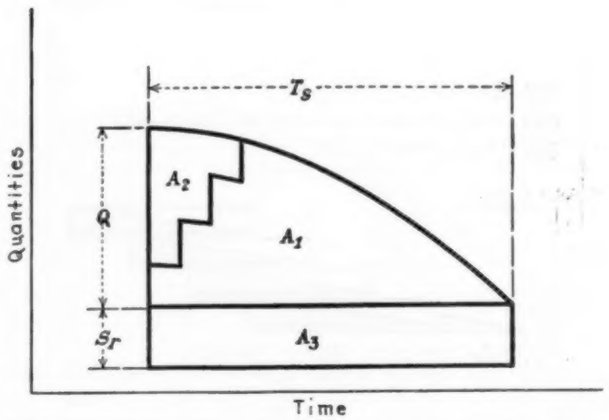


Fig. 13 Determination of Average Stock with Reserve Stock

never alters as the degree of completion of the average number of articles remains the same, one piece being started for each one completed.

Batch production, however, is so composed of a series of related operations, each having progressed to a different degree of completion at any instant, that the capital being invested in work in process is always increasing until production ceases. This can be well illustrated by Fig. 14.

Therefore it becomes necessary to determine the average amount of capital that is devoted to work in process throughout the manufacturing period. The average unit value of each batch can be expressed at any instant as

$$c'' = m + (l + o)k_s = m + hk_s(d_l + d_s)$$

The number of pieces in a batch is $Q/n$, where $n$ is the number of batches and the cost per batch at any instant is

$$c''Q/n$$

However, in order to determine the total investment charge all batches are completed in time $T_p$, and therefore the degree of completion factor is unity and the average value factor $k_a = {}^1/_2$. The cost per batch can thereby be expressed as

$$\frac{Q}{n} c'' = \frac{Q}{n}\left[m + \frac{h}{2}(d_l + d_o)\right]$$

The cost of the entire lot of $n$ batches, or the capital involved in work in process,

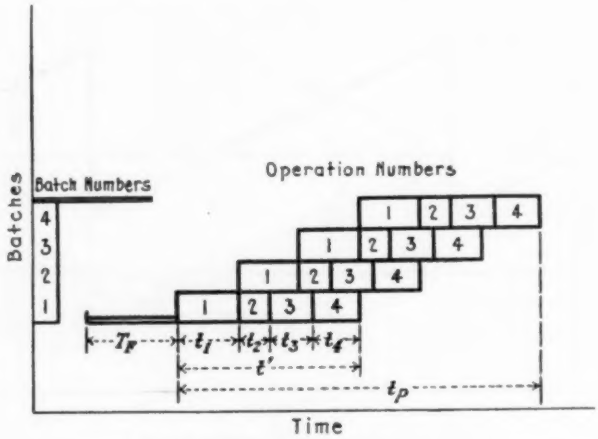


FIG. 14 THE SEQUENCE OF OPERATIONS

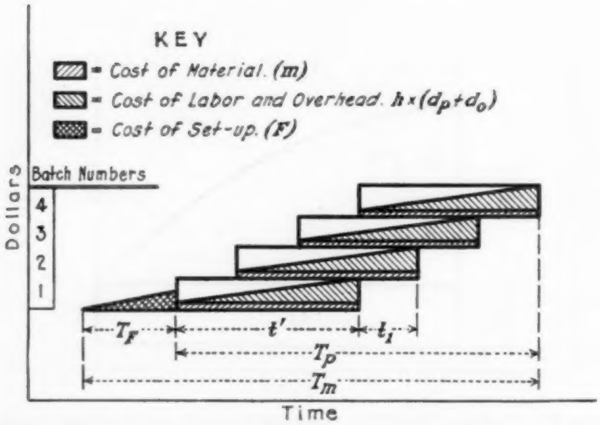


FIG. 15 THE INCREASE IN VALUE DURING WORK IN PROCESS

$$C_w = n\frac{Q}{n}\left[m + \frac{h}{2}(d_l + d_o)\right]$$

or

$$= Qc'k_p$$

where $k_p = c''/c'$. The time over which the investment charge applies is equal to the production time for each batch, including all operations, and will be designated by $t'$. The time required to complete the first operation ($t_1$) is that which separates the start of each batch. By inspection of Fig. 15 it will be noticed that

$$T_p = t' + (n-1)t_1$$

If

$$t_1 = a_1 t' \text{ where } a_1 = t_1/t'$$

$$T_p = t'[1 + (n-1)a_1]$$

$$t' = \frac{T_p}{1 + a_1 n - a_1}$$

or

$$t' = \frac{T_p}{a'}$$

where $a' = (1 + a_1 n - a_1)$. The expression for the investment charge upon capital involved in work in process becomes

$$I_w = Qc'k_p i_w \frac{T_p}{a'}$$

The interest rate $i_w$ applied to the capital in this equation is the same as used for inventories.

## SPACE CHARGE ON INVENTORY

Previously the investment charge $i_s$ on articles in stores has included several items, one of which represents a space charge based on a factor composed of rent, taxes, insurance, light, heat, etc., allotted to the stores department. This space charge should be separated from the investment charge as it depends on factors quite distinct from those governing the latter. In a paper published by R. C. Davis in *Manufacturing Industries*, August, 1926, a burden rate is applied to the space set aside for storing the maximum number of articles required to meet the consumption in any given turnover period, and the true space charge can be expressed in terms corresponding to those used in this paper as follows:

$$V = S_x B v T$$

where $S_x$ = maximum quantity that will be held in stock at the end of the manufacturing period
$B$ = space occupied by each unit
$v$ = factor representing the unit charge per day per cubic foot of space occupied
$T$ = period during which such articles are held in stock.

The maximum number $S_x$ of articles in stock, to which the factors for the space charge must be applied, is equal to the total number $Q$ of articles manufactured, minus the quantity withdrawn to meet the demand throughout the production period, plus any articles held as a reserve stock to meet emergencies, and can be expressed as:

$$S_x = Q - q + S_r$$

where the terms $q$ and $S_r$ are the same as previously derived. Accordingly this expression may be reduced, by substituting the proper values for each term, to:

$$S_x = Q\frac{Pf - Y_b}{P} + (f-1)Y_r$$

The time $T$ over which the space charge is applied is naturally equal to the length of the turnover period $T_s$ for any given production quantity $Q$, and as $T_s = Q/Y_a$ the final expression for the space charge becomes

$$V = \frac{Bv}{Y_a}\left[Q^2\frac{Pf - Y}{P} + Q(f-1)Y_r'\right]$$

However, if the space charge is applied to conditions where a variable demand exists, as will be discussed later, the expression for the maximum number of articles $S_x$ must be derived in a different manner. In this case (see later paragraph), the stock on hand at the end of the manufacturing period $S_p$ is equal to

$$S_p = Q - \int^{T_p} YdT$$
$$= Q - Y'p$$

By substituting this expression for the terms $(Q - q)$ in the previous equation, the value for the space charge can be written as

$$V = \frac{Bv}{Y_{as}} Q \left[ Q - Y'_p + (f - 1)Y'_r \right]$$

### Deterioration

Certain classes of products will deteriorate to a greater extent than others if kept in stock for too long a period or under unsuitable conditions. The loss incurred from such deterioration is justifiably chargeable against the total cost of the lot, and should be evenly distributed as an additional charge on each unit. Deterioration cannot be accurately calculated and must be estimated from experience; however, if expressed in the form of a ratio and applied as a percentage coefficient to the production quantity, a sufficiently accurate factor will be available for given conditions. Should conditions change such a factor must be altered to suit. Whenever deterioration is a vital factor experience will give reliable data. Deterioration is peculiar in one respect that it not only is a loss and an additional charge on each unit, but also requires an increase in the production quantity to make up for that loss without reducing the number of articles in stock below an amount supposedly great enough to satisfy the demand throughout the full period. The coefficient for deterioration may be expressed by

$$\Delta = \frac{Q_s}{Q_e}$$

where $Q_s$ equals the number of articles required to meet the demand $Y_aT_s$ in the period $T_s$, and $Q_e$ equals the Economic Production Quantity. Hence

$$Y_aT_s = Q_s = Q_e - Q_d$$

where $Q_d$ is the number of articles that deteriorate or are a total loss. The value of this loss depends upon the solution, whether approximate or exact, for the economic production quantity. If exact the loss $D$ becomes

$$D = Q_dU$$
$$= Q_e(1 - \Delta)U$$

If approximate,

$$D = Q_d\left(c' + \frac{F}{Q_e}\right)$$
$$= Q_e(1 - \Delta)\left(c' + \frac{F}{Q_e}\right)$$

The value for the sales period must be altered to suit the first relation and becomes

$$T_s = \frac{Q_e - Q_d}{Y_a}$$
$$= \frac{\Delta Q_e}{Y_a}$$

and this form must be used when deterioration is included in the general formula.

### Obsolescence

Obsolescence is an important factor which can affect or limit the production quantity markedly. If the turnover period extends beyond a certain limit it is quite possible, in certain lines of industry, to find that the demand will suddenly cease or alter due to seasonal conditions, improvement in design, or the whim of the customer. Therefore such articles as are not sold at that time will have no market and will remain on the manufacturer's hands indefinitely, unless scrapped for whatever value they may have. If the conditions involving obsolescence are known beforehand, the quantity to be produced becomes limited by a time factor, provided the normal sales period is greater, and can no longer be determined upon the principle of economic production quantities. This is due to the fact that the turnover period is not an independent quantity but depends upon the demand and the number of pieces produced and placed in stock. The quantity $Q_\theta$ to be produced to meet these conditions can be expressed by the relation

$$Q_\theta = Y_aT_\theta$$

where $T_\theta$ is the time at which obsolescence commences.

However, if this time limit is sufficiently remote, and yet approximately determinate, so that two or more turnover periods may pass before obsolescence becomes effective, it is possible to apply the economic production quantity methods to this case. The result is that each turnover period is slightly extended so that practically the remaining time is divided into a given number of equal periods, the quantity produced in those periods being the nearest possible to the ideal production quantity. Again it is advisable to express the obsolescence factor as a coefficient of the economic production quantity as its exact value is never known.

If $Y'_{eb}$ is approximately the number of pieces that can be sold, and $Q_e$ is the unrestricted economic production quantity, the number of whole turnover periods will be represented by

$$n' = \frac{Y'_{eb}}{Q_e}$$

The coefficient of obsolescence can then be expressed as

$$\theta = \frac{Y'_{eb}}{n'Q_e} \quad \text{or} \quad \frac{Y'_{eb}/n'}{Q_e}$$

As the only effect of obsolescence is to alter the number of pieces to be produced in a given period, it will appear only as a corrective factor applied to the time value of the turnover period. Hence if

$$Y_aT_s = Q_e$$
$$Y_a\theta T_s = \theta Q_e = \frac{Y'_{eb}}{n'}$$

but

$$\theta Q_e = Q_{eb}$$

hence

$$T_s = \frac{Q_{eb}}{Y_a\theta} = \frac{T_\theta}{n'}$$

This expression should be substituted for the usual expression for $T_s$ in the total unit cost and solved for $Q_{eb}$ which replaces $Q$ throughout without further change in form.

### Variable Demand

The rate of consumption or sales has of necessity been assumed as a definite or average amount for a year which has then been reduced to terms of a month, week or day to suit the requirements of a given formula. This practice only approximates the actual conditions in an industry as it takes no actual account of the seasonal variations in the demand nor of the major trend in that industry except as the yearly average may be arbitrarily changed. Therefore it is important that some definite method be established which will permit a correction of the demand factor to suit the changes from season to season. In certain parts of the year the demand will be great and in others it will be less, and

unless the formula for the Economic Production Quantity can take into account such differences, it will not represent that quantity which can be produced at the lowest possible unit cost. This stands to reason because too many articles may be produced at a time when the demand is slack and the investment and

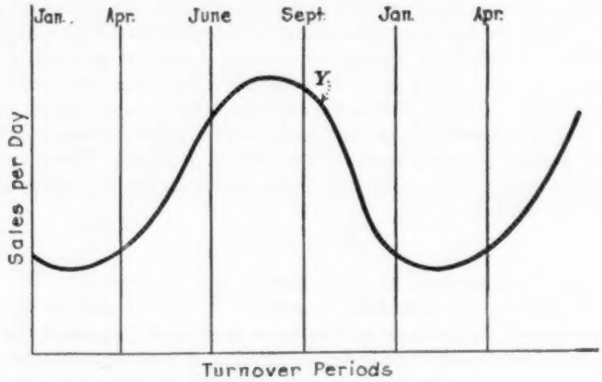


Fig. 16 The Daily Demand Curve ($Y$)

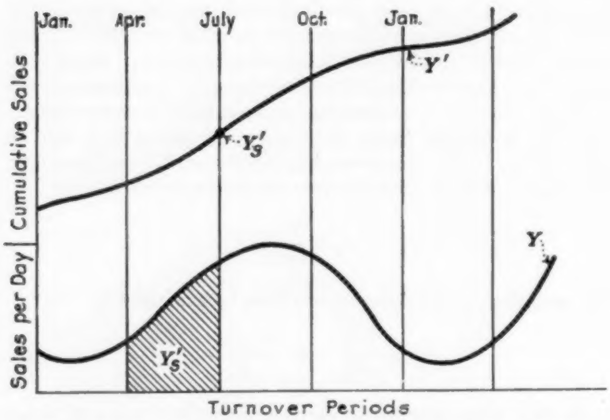


Fig. 17 The Cumulative Demand Curve ($Y' = \int YdT$)

storage charges on the finished articles in stock will be increased as they will remain in inventory for a longer time and the additional charge cannot be absorbed elsewhere. The converse will be true if the demand in a given period increases, so that an unnecessary additional process lot may be required which will involve a further expenditure of working capital sooner than ordinarily expected.

A solution of this problem is to be found through forecasting the volume of business for the immediate future. Considerable study has been made along these lines and it has been proved that reliable information and data can be obtained for determining the prospective demand for any period. The methods of making such an analysis do not concern us here as many valuable articles and books have been written on this subject, and the reader is referred particularly to two books by Mr. Joseph H. Barber of the Walworth Co.: Budgeting to the Business Cycle, and Economic Control of Inventory. The mathematical analysis based upon this work will show how the proper corrective factors may be introduced and applied to terms already existing in the formula for the Economic Production Quantity. The actual determination of these quantities involves independent calculations.

By the method of forecasting a typical curve may be obtained which will show the probable number of articles $Y$ that can be sold on any day throughout the year, which can be expressed by

$$Y = f(T) \qquad \text{(Fig. 16)}$$
$$= a + bT + cT^2 + dT^3 \ldots, \text{etc.}$$

From this, it is possible to determine the total number of articles $Y'$ required for any period which extends for a time $T$, by calculating the area under the demand curve, so that

$$Y' = \int_0^T YdT \quad \text{(Fig. 17)}$$

When $T$ becomes equal to $T_s$, this quantity represents the number of articles that must be placed in stock to meet the requirements of the consumption period and naturally must equal the Economic Production Quantity $Q$.

The expression which represents the changing condition in the stock as finished articles are withdrawn from inventory and applied to shipments may be written for any instant of time $T$, as

$$S = Q - \int_0^T YdT \quad \text{(Fig. 18)}$$

The average stock factor $k$ represents the rapidity with which articles are to be withdrawn, and is a function of the shape of the stock curve $S$. If withdrawals are greater earlier in the period than near the end, the curve $S$ is concave upward and the value of $k$ will be less than $1/2$; if the greatest withdrawals occur near

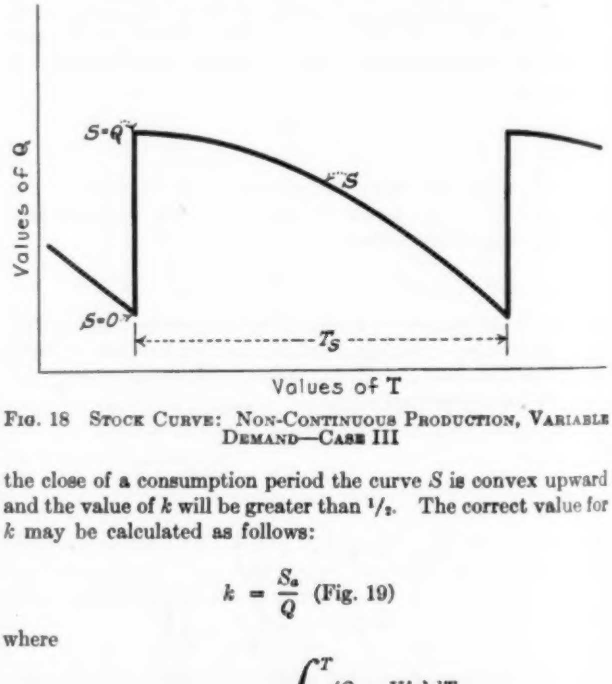


Fig. 18 Stock Curve: Non-Continuous Production, Variable Demand—Case III

the close of a consumption period the curve $S$ is convex upward and the value of $k$ will be greater than $1/2$. The correct value for $k$ may be calculated as follows:

$$k = \frac{S_a}{Q} \quad \text{(Fig. 19)}$$

where

$$S_a = \frac{\int_0^T (Q - Y'_T)dT}{T}$$

and represents the average ordinate for the curve $S$ between the limits of 0 and $T$.

The expression for $T_s$ when variable demand is to be considered can be derived from the fact that at the end of the consumption or turnover period, when $T$ becomes equal to $T_s$, the entire number of articles manufactured have been completely withdrawn from stock so that $S$ equals zero. Hence

$$S = Q - \int_0^{T_s} YdT = 0$$

$$\frac{Q}{T_s} = \frac{\int^{T_s} Y\,dT}{T_s}$$

but if $Y_{as}$ represents the average demand per day for a given period, it is equal to

$$\frac{\int_0^{T_s} Y\,dT}{T_s}$$

and can be substituted in the above equation so that

$$T_s = \frac{Q}{Y_{as}}$$

It will be noticed that both the terms $k$ and $T_s$ are dependent variables upon $Q$ and cannot be reduced to numerical values until $Q$ has been determined, as each requires an independent solution. However, a close approximation can be reached by first determining $Q$ for constant demand and solving for $T_s$ under those conditions. Then by substituting these values in the appropriate equations above, reasonable values for $S_a$ and $Y_{as}$ may be obtained, from which the desired values for $k$ and $T_s$ for conditions of variable sales may be calculated.

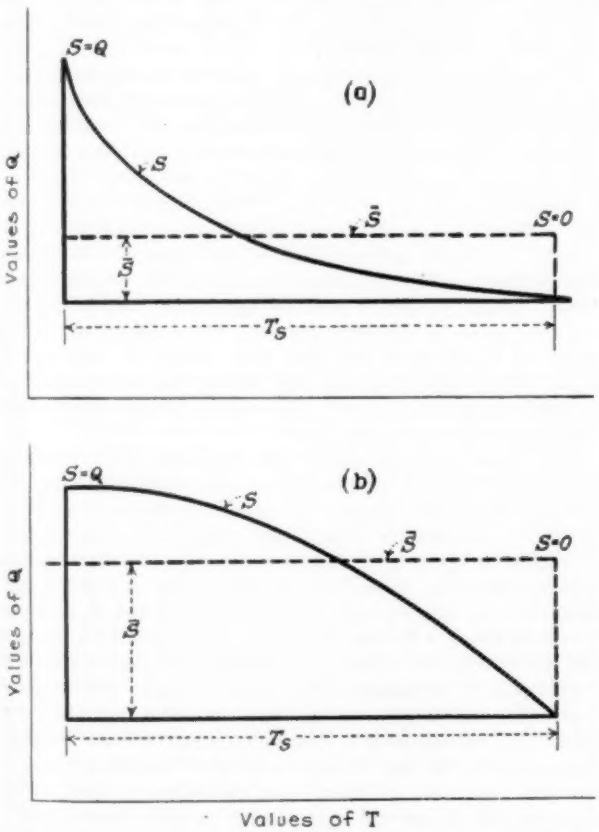


Fig. 19 Variations in Stock Curve and Average Stock, Variable Demand

This mathematical analysis is perfectly justifiable and illustrates further certain underlying factors; however, if the mathematical expressions for these factors be incorporated in the general formula for the Economic Production Quantity $Q$, the resulting equation will be so complicated that the solution will be of little practical value.

## Expressions for the Ultimate Unit Cost

Accordingly the Total Unit Cost of producing and storing manufactured articles is equal to the sum of the various cost charges derived in the foregoing paragraphs, and may be written in the following two forms, showing the relation of all items.

$$U = c' + \frac{F}{Q} + \frac{Q(k_s + f - 1) - Y'_r(f-1)}{Q}\left(c' + \frac{F}{Q}\right)\cdot\frac{i\,\Delta Q}{\theta Y_a} + \frac{Qc'i}{Q}k_p\frac{Q}{P_a'} + \frac{vB\,\Delta Q}{Q\theta Y_a}\left[Q\,\frac{Pf - Y_a\,[1-(1/n)]}{P} - Y'_r(f-1)\right] + \frac{Q(1-\Delta)\left(c' + \frac{F}{Q}\right)}{Q} \quad \text{(Approximate form)}$$

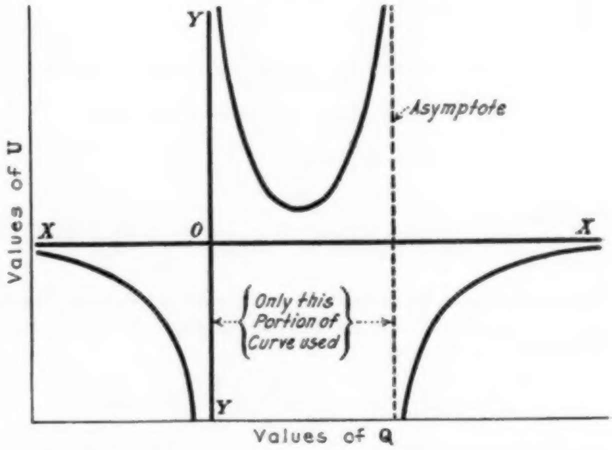


Fig. 20 Ultimate Unit-Cost Curve, Exact Form

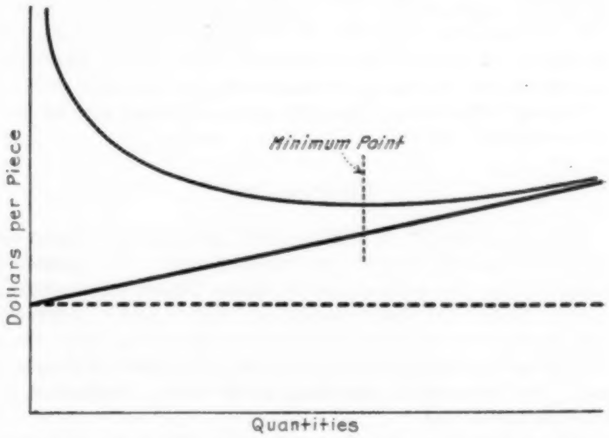


Fig. 21 Ultimate Unit-Cost Curve, Approximate Form

$$U = c' + \frac{F}{Q} + \frac{Q(k_s + f - 1) - Y'_r(f-1)}{Q}\,U\,\frac{i\,\Delta Q}{\theta Y_a} + \frac{Qc'i}{Q}k_p\frac{Q}{Pa'} + \frac{vB\,\Delta Q}{Q\theta Y_a}\left[Q\frac{Pf - Y_a\,[1-(1/n)]}{P} - Y_r'(f-1)\right] + \frac{Q(1-\Delta)U}{Q} \quad \text{(Exact form)}$$

## Analysis of Formulas

A graphical analysis of these equations shows that the effect of adding the terms $I_s/Q$, $I_w/Q$, $V/Q$, and $D/Q$ to the manufacturing cost $[c = c' + (F/Q)]$ alters the position of the curve $c$ as

described in an earlier paragraph so that the resulting curve for values of the ultimate unit cost $U$ plotted with $Q$ for abscissa approaches, in the case of the exact solution, asymptotes parallel

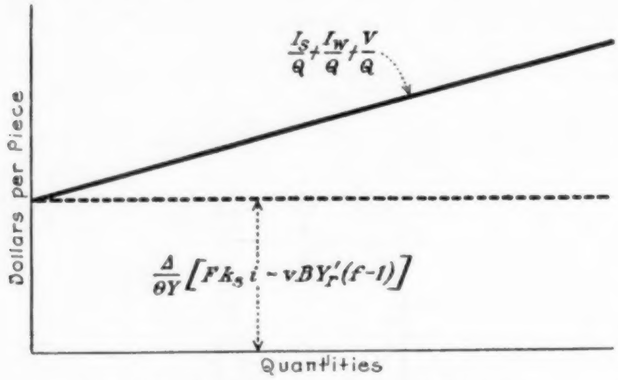


FIG. 22 INVESTMENT AND STORAGE CHARGES

to the $Y$-axis at the points where

$$Q = 0 \text{ and } Q = \frac{\Delta\theta Y_a P}{i\left[(k+f-1)\Delta P - \theta Y_{as}\frac{[1-(1/n)]}{2}\right]} \quad \text{(Fig. 20)}$$

and approaches as an asymptote, in the case of the approximate solution, a straight line inclined at an angle to the X-axis, represented by the equation

$$U = c'(2-\Delta) + \frac{I_s}{Q} + \frac{I_w}{Q} + \frac{V}{Q} \quad \text{(Fig. 21)}$$

which crosses the $Y$-axis at the point where $U = c'(2-\Delta)$ instead of approaching an asymptote parallel to the X-axis represented by a straight line $U = c'$, as in the case where $U$ equals only the manufacturing cost $[c' + (F/Q)]$. In both cases the expression for $U$, then, has a minimum point beyond which the investment and storage charges increase detrimentally without giving any added protection or business advantage and become an increasing burden.

## Discussion

JOHN C. SOMERS.[4] A definite need exists in manufacturing industries for methods of accurate measurement. The equations presented by the author give a simple means of measuring various items and then calculating, with relative accuracy, that quantity which can be produced at a minimum cost. Thus the author has made a definite contribution to industrial measurements and has assisted materially in the definite application of these measurements.

The secret of economical operation is a rapid rate of capital turnover. This is possible only with good control over raw and finished inventory. The chief advantage in the application of the author's equation is that a better control over the economics of production is obtainable, which produces similar effects in stores inventories and thus tends to speed up the rates of capital turnover. This is a decided advantage to all organizations particularly in the highly competitive field with a low margin of profit.

The writer has one criticism which is applicable to other equations in connection with the laws of management. The author points out that the solution of the general problem by minimum cost quantities has four definite applications. In any of these applications the presentation of the equation loses sight of certain aspects of the technique of solving the problem. This has reference to the terms, or combination of terms, that must be definitely determined in order to substitute into the equation. These variables, although very rarely indeterminates, require considerable skill in evaluating. The problem is admittedly simple in form, there being very definite equations for use. Nevertheless a certain amount of technique, resulting from experience, is essential to making the right substitutions. Referring particularly to the determination of fixed cost, sales demand, direct cost, and various other items, either for a specific process or an individual part, clearly indicates the obvious difficulty.

In the writer's experience, it has been useful to calculate the different values of $Q$ for the various values of the variables, such as above referred to, and then to chart these calculations for present or future use. In this way, the supply of a certain item for a definitely known period can be easily determined and economically manufactured with a single set-up. The quantity could be calculated for certain conditions, a slight variation in the conditions having a marked effect on the value of the minimum cost quantity.

In making these calculations, it must be remembered, that, in a great number of cases, the value $Q$ is the output, for a certain period, of only a percentage of the machinery that could be used. Hence the unit cost, including labor, material, overhead, preparation, and investment charges on inventory and work in progress, is somewhat fictitious, since there are additional items of cost that will add to the final cost as well as decrease the profit margin. In the larger organization, for example the electric manufacturer, this is a serious problem as the economic production quantity may be such on paper only and in the last analysis it may be the very opposite. Reference to any of the equations for $Q$ clearly indicates this. Since the unit cost is in the denominator, thus varying inversely as the square of $Q$, a small decrease in the unit price would have a considerably larger increase in the value of $Q$.

It is more or less apparent that the difficulties of applying the correct unit cost will be less where a system of standard cost is in operation. In this case there will always be a correct unit cost available for substitution in the equation. It will invariably be up to date, that is, adjusted to suit correct conditions. However, where the manufacturing period for the minimum cost quantity will extend over a period of over one month or more, a further corrective factor should be applied. This introduces the causes of inaccurate standard costs. For the purpose of discussion of the paper it might well be mentioned that current prices of materials should be used, and not a figure that will represent a speculative profit or loss. Further, in cases where the cost of material is more than 50 per cent of the total unit cost, additional care should be exercised to see that the cost of material is not based on bulk quantity costs, using the wrong weight or other quantity units.

The importance of using some standard cost system cannot be stressed too much. Also, with the larger manufacturer these standards, say on 10 to 150 thousand items, are invaluable for other control purposes, but must be handled adeptly when substituted into an equation which will arbitrarily decide that the requirements for twelve months are to be produced in two months, say, instead of six. This point can be emphasized by stating that in the writer's experience of making similar substitutions, the cost accountant had one amount, the engineer another, and the manager still another, which, incidently, was the more accurate.

The value of $Q$, the economic production quantity, sometimes is almost an indeterminate. This is true, referring to Equation

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[1], when $Y > 0$, $k = 1$, $f < 1$ and $n = 1$. Consumption would either be very small here or equal to zero, there would be no sales demand, an insufficient reserve stock to take care of the manufacturing period, and all articles are manufactured in one lot and delivered to stores. These conditions are not abnormal and occur frequently in the large organizations. To try to calculate $Q$ in such instances is not necessarily of much value, since the determination of the economic production quantity can be decided upon by a knowledge of local conditions in the shop.

A definite advantage of the computations, outlined by the author, is the knowledge of valuable schedule data usually quite unknown. It gives the size of quantities which are released for manufacture in the usual manufacturer's order. These are usually set up in a practical or rule of thumb method which invariably considers only the convenience of the form of the order. A definite formula from which this quantity is determined eliminates, to a degree, this rule-of-thumb method, at the same time increasing the economics of the operating cycle of manufacture.

The introduction of such calculations sometimes overlooks the proper studying of the productive machinery. It is also easy to neglect engineering changes, necessary tests, delays, interruptions, and also inefficient operation. These factors are important and can easily unbalance the production schedules that are worked up from empirical formulas. However, the economic production quantity calculations, along scientific lines, are of value to production control. The quantities can be calculated for various demands, production rates, unit costs, engineering changes, and reprocessing of work. These can be plotted or tabulated and used in the system of production control, and can be incorporated into the current standards for such work.

J. E. Hires.[5] The author seems to have worked out a very complicated formula for determining the minimum quantity of product which can be produced at the lowest total unit cost. There are many conditions which this formula does not cover, such as sometimes found in plants manufacturing a multitude of products, each bearing a different profit per unit. Also, many manufacturers use raw materials which it is necessary to order a year or so in advance, for instance one concern uses hickory handles in its tools. Such conditions often necessitate the carrying of considerable stocks. In most cases the overhead can be divided into two classes: fixed overhead, which includes rentals, administration expense, interest on investment, insurance, etc., and unit overhead, which covers material, labor, interest on inventories and work in progress, etc. With the above overhead and with the unit sales-price, a simple formula for minimum quantity units can be derived for each article.

F. Richmond Fletcher[6] and O. Cammann, Jr.[7] From the point of view of abstract science, the author has accomplished a thorough piece of work in assembling into one formula most of the factors which determine the true economic production quantity for any industry. An abstract analysis of all of the theories involved, such as contained in the paper, had to be made to prove the mathematical correctness of the theories. Practical applications were very naturally not within the scope of the paper. The writers have attempted to find the economic production quantity for a specific manufactured article by inserting actual numerical quantities in the author's formula.

In order to have actual values to use in this formula, figures for an imaginary manufactured article were developed as shown in Table 1.

TABLE 1 DATA OF IMAGINARY MANUFACTURED ARTICLE FOR TESTING RAYMOND FORMULA

| | | |
|---|---|---|
| Material | \$0.300 | |
| Labor | | |
| Operation 1 | 0.005 | |
| Operation 2 | 0.020 | |
| Operation 3 | 0.025 | |
| Burden | | |
| Operation 1 | 0.010 | |
| Operation 2 | 0.060 | |
| Operation 3 | 0.040 | |
| | \$0.460 | $C'$ |
| Set-up, Clerical, etc. | \$1.100 | |
| Operation 1 | 2.000 | |
| Operation 2 | 5.000 | |
| Operation 3 | 0.100 | |
| | \$8.200 | $F$ |
| Storage charge per sq. ft. per day | \$0.00057 | $v$ |
| Space occupied by each unit, sq. ft | 0.120 | $B$ |
| Daily rate of production, units | 400 | $P$ |
| Average daily demand, units | 10 | $Y_a$ |
| Assume $S'_r/S_m$ | 1 | $f$ |
| Fixed charge rate per day | \$0.000333 | $i$ |
| Assume all one batch | 1 | $n$ |
| $\dfrac{\text{Material} + \frac{1}{2}\,(\text{labor} + \text{overhead})}{\text{direct cost}} = \dfrac{0.300 + 0.080}{0.46}$ | $= 0.826$ | $K_p$ |
| Obsolescence not considered | 1 | $\Theta$ |
| Assume constant demand | $^1/_2$ | $k$ |
| $t' = Q/P$ (all one batch), $Q/Pt'$ | 1 | $a'$ |
| Deterioration not considered | 1 | $\Delta$ |
| $Q - S_m = Q - \left(\frac{Q}{400} \times 10\right)$ | $Q - \frac{Q}{40}$ | $Y'_r$ |

(Since $f = 1$ in this example, $Y'_r$ drops out of the equation)

At the outset we found some difficulty in adequately defining the terms used in Formula [1]. This was undoubtedly due to a somewhat hazy knowledge of mathematics; but if the average production man is to make practical use of it, the author should include a description of the meaning of the letters or terms similar to that shown below:

$F$ = preparation cost, dollars = plan and schedule, issue order, tool preparation, set-up, etc.

$P$ = rate of production, pieces per day

$$\Theta = \frac{Y'_{os}}{n'Q_s} = \frac{\text{number of pieces which can be sold}}{\text{number of whole turnover periods} \times \text{unrestricted econ. prod. quan.}}$$

$Y_a$ = average demand, pieces per day

$Y'_r = Q - S_m$ = (economic production quantity)—(minimum stock)

$$f = \frac{S'_r}{S_m} = \frac{\text{stock on hand at ordering point}}{\text{minimum stock}}$$

$S'_r = S_m$ + emergency stock

$i$ = interest rate, daily

$C'$ = unit material cost + unit labor cost + unit overhead cost

$$k = \frac{S_a}{Q} = \frac{\text{average stock}}{\text{economic production quantity}}$$

$= {}^1/_2$ for constant demand

$$\Delta = \text{coefficient of deterioration} = \frac{Q_s}{Q_e}$$

$$= \frac{\text{number of articles to meet } Y_a \text{ in sales period of \dots days}}{\text{economic production quantity}}$$

$n$ = number of batches in one lot

$$k_p = \frac{m + (l + o)k_a}{C'} = \frac{\text{material} + \dfrac{(\text{labor} + \text{overhead})}{2}}{C'}$$

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[6] Engineering Partner, Scovell, Wellington & Co., Boston, Mass. Assoc-Mem. A.S.M.E.

[7] Member of Staff, Scovell, Wellington & Co., Boston, Mass. Jun. A.S.M.E.

$A' = \dfrac{Q}{P_i'} = \dfrac{Q}{P \times \text{(production time for each batch)}}$

$v$ = factor representing unit charge per day per cu. ft. of space occupied

$B$ = space occupied by each unit, sq. ft.

$Q$ = Economic Production Quantity

The specific values shown in Table 1 were substituted in Formula [1] and the equation solved for $Q$, as follows:

plete the stock $^1/_{40}$, the inventory charges against work in process are negligible. Quantities are plotted horizontally, the quantity at $T$ representing the quantity required to meet the sales demand for one year. The cost per unit, in dollars, has been plotted vertically.

The preparation-cost curve is determined by dividing the preparation cost, \$8.20, by the quantity. This will naturally be high for the lower quantities, and low for the higher quantities.

Values for the unit cost of fixed charges on inventories, and

$$Q = \sqrt{\frac{FP\{2\Theta Y_a - \Delta[\Theta Y_a + Y'_r(f-1)i]\}}{C'i\left[(k+f-1)\Delta P - \Theta Y_a\left(\dfrac{1-\frac{1}{n}}{2}\right)\right] + C'i\Theta Y_a\dfrac{k_p}{a'} + vB\Delta\left[Pf - Y_a\left(1-\dfrac{1}{n}\right)\right]}}$$

Simplifying as $\Theta$, $\Delta$, $f$, $a'$, and $n = 1$

$$Q = \sqrt{\frac{FP\{2Y_a - [Y_a + 0]\}}{C'i[(k+0)P - 0] + C'iY_ak_p + vB[P-0]}}$$

$$= \sqrt{\frac{FPY_a}{C'i[kP + Y_ak_p] + vBP}}$$

Substituting from Table 1,

for the storage cost per unit have been computed as if the whole year's supply were manufactured at one time—that is, as if an order of 3000 units were put through the factory at once. The cost per unit to carry the whole year's supply has been plotted on the basis of an annual fixed-charge rate and an annual charge per square foot for storage. The fixed-charge amount has been divided by 2 (see $K = {}^1/_2$ in the author's formula), because the average inventory is assumed to equal one-half of the maximum inventory. The maximum requirements for storage

$$Q = \sqrt{\frac{(8.2)(400)(10)}{(0.46)(0.000333)\left[\dfrac{400}{2} + (10)(0.826)\right] + (0.00057)(0.12)(400)}} = \sqrt{55300} = 744$$

After a somewhat tedious computation, we arrived at a value for $Q$ which we attempted to check by a rule-of-thumb method similar to that which any production man would use. In making this check calculation, we began to wonder whether or not it were possible to devise a simple method of determining an economic production quantity, which would be sufficiently accurate for all practical purposes, and which would not omit any of the important variables in the author's formula.

It appears that the author does not consider the question of idle plant capacity in determining the economic production quantity, with which we agree. He starts with what he calls "direct cost," which includes labor, material, and overhead. From the overhead item he deducts fixed charges on inventories, such as interest on investment, taxes, insurance, etc., and also all storage and handling charges. Consequently, for any given article at a given time, this direct cost does not vary with the quantity produced.

The writers recognize two principal types of variable entering into the equation for the economic production quantity. The first type is that in which the unit cost decreases as the quantity produced increases, such as cost of set-up, preparation of the order, and all other operations necessary to get the order under way in the factory. The second type is that one in which the unit cost increases as the production quantity increases. It reflects the increased carrying charge on large inventories, resulting from the higher fixed charges on a greater volume produced at one time, and from the added cost of storing the product in larger quantities.

The first type of variable which the author calls "preparation cost" is a fixed amount for each order put into the factory, and therefore the preparation cost per unit varies inversely as the number of units produced on that order.

Taking the figures from Table 1, we have worked out an approximate solution by a simple graphical method shown in Fig. 23. We have assumed, as we did for the author's formula, that the sales demand is constant. As the manufacturing time is relatively small, compared to the time required to complete the stock... 

space are assumed to be needed for the entire period that the stock is held. If this does not hold true, an arbitrary reduction should be made to represent the ratio of average storage space to maximum storage space. The storage cost and the fixed charge cost may be represented by lines drawn through points

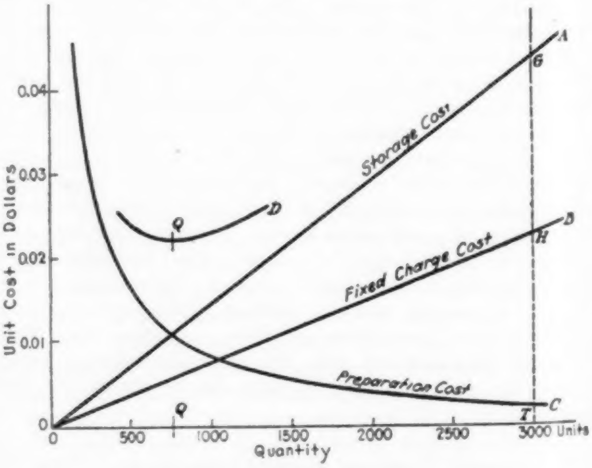


Fig. 23

$G$ and $H$, determined for one year, to the origin, because these two variables increase directly with the number of units per order.

The second type of variable, representing the storage cost and the fixed-charge cost, depends on the size of the inventory and on the length of time that that inventory is kept on hand. This charge is therefore directly proportional to the time that the inventory is kept on hand, and increases as the length of time increases.

It will therefore be seen that while an increase in the number of units on a given order will decrease the unit preparation cost, it will at the same time cause an increase in the storage and

fixed-charge costs per unit. Our problem therefore as regards these two types of variables is to determine that quantity which will reduce the unit preparation cost, plus the unit storage and fixed-charge costs, to the minimum.

If we take any given quantity shown in Fig. 23, and read off the unit cost of preparation from curve $C$, and the unit cost for fixed charges and storage as denoted by line $A$, we will have the total cost for that quantity incurred through preparation, through storage, and through fixed charges. This amount for different quantities may be plotted and a curve drawn representing such amounts, as curve $D$. This curve will invariably start at the left-hand side of the chart with a high unit cost, decreasing to a certain point, and then start to increase again as shown. When this curve reaches the minimum point (750 units approximately), as shown on the chart, it indicates the economic production quantity for the variables in question.

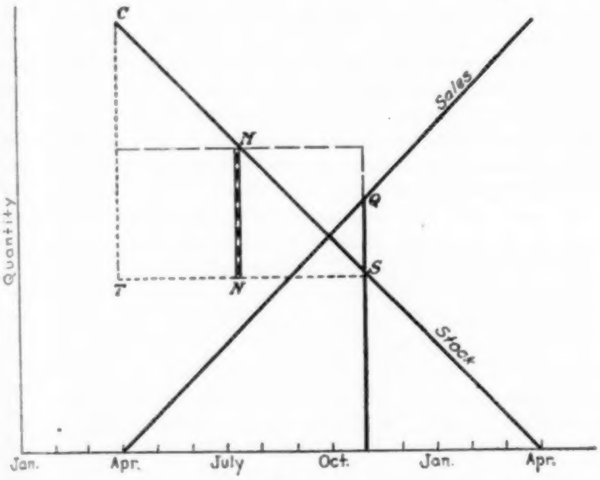


FIG. 24

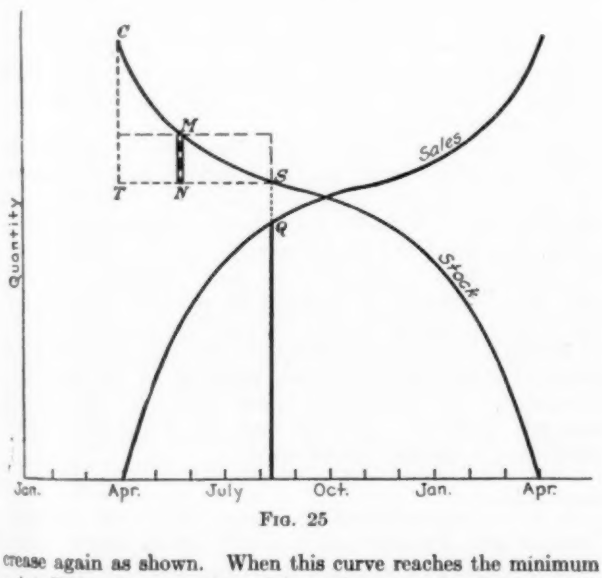


FIG. 25

The economic production quantity thus found may be affected still further by three other variables. These are the variable sales demand, deterioration, and obsolescence, as mentioned by the author.

It is obvious that if the economic production quantity results in a figure greater than that at which it is possible to sell before the article of manufacture becomes obsolete, the number that can be sold prior to obsolescence is the controlling factor, and the economic quantity is not to be considered. Likewise, if the economic quantity will produce a volume which will remain in stock longer than the nature of the product warrants, without deterioration, this will reduce the economic quantity and become the controlling factor.

The determination of the effect of a variable sales demand is somewhat more complicated than that of the other two factors just mentioned, but a solution sufficiently accurate for all practical purposes may generally be arrived at. As the author has suggested, it is advisable, first, to determine the economic quantity for a constant sales demand. Next, the cumulative sales forecast (Fig. 17) should be plotted as shown in Figs. 24, 25, and 26 and from this, the stock curve which is the reverse or complement of the sales curve. Then apply the economic quantity already computed for a constant sales demand to the cumulative-sales curve $Q$ and determine the corresponding position on the stock curve $S$. Through point $S$ on the stock curve, draw a horizontal line. The area $TCMS$ above this horizontal line will represent approximately the stock condition for the turnover period. Next, determine (visual approximation will generally be sufficient) the average volume of stock, and recalculate the position of points $G$ and $H$ on Fig. 23, for this new average stock value. The ratio of the length of the line $MN$ to $CT$ is the $K$ introduced by the author. It is used as the writers have used the factor $^1/_2$ (or divide by 2) in determining the average stock upon which to compute the fixed-charge costs.

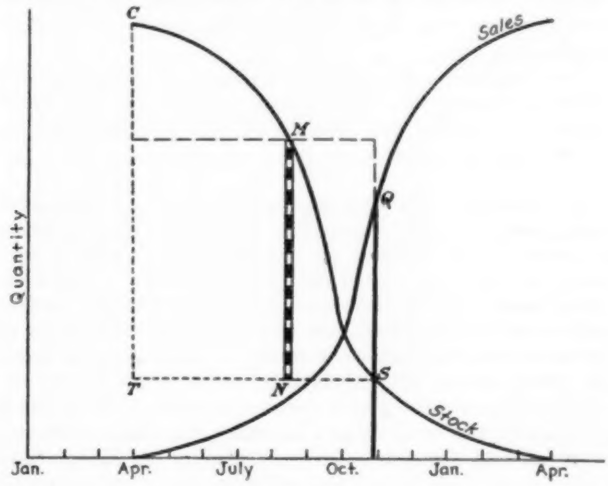


FIG. 26

The economic quantity found by this method will more nearly reflect a varying sales demand than that found by asuming a constant sales demand. It must be remembered, however, that this second solution is applicable only to periods in which the stock conditions are similar to those represented by the portion of the stock curve applying to the turnover period, although lines $A$ and $B$ in Fig. 23 are worked out for a period of one year.

As the author has endeavored to include in his formula all factors which may affect the economic quantity, some consideration should be given to the character and size of transportation devices and to the varying cost, both in labor and storage space, resulting in their use at less than normal capacity. For example, the shoe industry finds that processing shoes on racks capable of holding 12 pairs is most convenient and economical. Under these conditions if the economic production quantity resulted in the use of a 12-pair rack with only 4 pairs on it, the trans-

portation charge would be materially increased but that additional cost is not reflected in the formula.

Robert T. Kent.[3] This question of economic lot sizes is of extreme importance to executives, and we all would be deeply indebted to the man who presents a satisfactory formula to fit all conditions. One trouble with all attacks on this problem seems to be that one very practical aspect of the phase of determining economic lot sizes has been ignored. Most of the solutions have consisted in the consideration of a single item of the problem. That is all very well for the manufacturer with a single line, or a number of items of similar character. For the manufacturer who is making a rather diversified line of articles, perhaps in large quantities, for a number of different customers, the problem is somewhat complicated. Suppose that the manufacturer is making two articles in large quantities for two different customers. Each one is seasonal in character, and each has a peak which more or less overlaps the other. The machine capacity is sufficient to take care of that demand throughout the year, or perhaps throughout the seasonal period, but the situation is complicated by the fact that each customer demands deliveries to meet his sales requirements, and economic lot sizes, very often, must be disregarded in order to conform to the sales policy.

That man will make a valuable contribution to industry who devises a formula that will determine economic lot sizes, based on machine capacity and complicated by overlapping demands for that machine capacity.

The Author. The discussions submitted on my paper have added greatly to its value, one of its main objects being to gather as much outside criticism as possible, in order that it may reflect the point of view of the greatest number of engineers. Many simple expressions have previously been derived; in fact twelve writers have developed fifteen different expressions of the same general character and similar to the forms given under the paragraph on existing formulas. The graphical solution suggested by Messrs. Fletcher and Cammann is an excellent addition to the problem and simplifies the solution greatly when variable demand is to be considered. If the problem involving variable demand is worked out mathematically, the expression for $Q$ results in an equation of the sixth degree in terms of the cosine, which for practical purposes is useless. One expression naturally could be developed which would cover a multitude of products manufactured by any one company, but would probably be even more complicated than the expression for variable demand referred to above. It seems, therefore, most desirable to determine the simplest and most universal expression for the economic production quantity, applied to but one unit of the product, putting it first into a satisfactory form for practical application. The solution of the theoretical Formula [1] would unquestionably involve tedious calculation, owing to the complex composition of its terms; however, it is presupposed that this formula would be simplified to suit the conditions of any particular industry by eliminating factors and terms which do not apply, before numerical values are substituted for the remaining terms. That being accomplished, results may be obtained through simple arithmetic, in a short time.

As the purpose of this paper is to expose all controlling and contributory factors and arrange them in an expression which will illustrate their relation to each other, it was necessary to go into considerable detail in order to explain the derivation of each term. Therefore it was undesirable to give merely a list of these terms without explaining their origin; in fact half of the paper is devoted to this purpose. Naturally, considering the form in which the theoretical Formula [1] stands, special technique and understanding of the problem are required. It is hoped that in the end a form may be developed for practical purposes, requiring no special knowledge of the conditions, and resulting from these discussions and further suggestions that may be submitted.

In most cases the value used for the average storage space must be the maximum number of articles placed in stock at the end of the production period; however, should special conditions arise whereby this space is used for storing other articles after a certain number of the original articles have been withdrawn, this condition may be corrected for by a coefficient. Internal transportation does not affect the final value of the economic production quantity, because even though the total cost of the production quantity is affected by this factor which depends upon $Q$, when reduced to the total ultimate unit cost this factor becomes a constant not involving $Q$, and when differentiated, becomes zero. Likewise, idle plant capacity is not a factor affecting the economic production quantity, as accountants generally agree that the loss due to idle equipment is first, a penalty on the sales department; second, an item only of the profit and loss account; and third, one of the risks of doing business and consequently a factor not within the control of the factory management.

The present paper is only a preliminary step in consolidating all previous efforts toward deriving a suitable method of determining the economic production quantity. Naturally it is necessary first to determine the theoretical relationship of each factor, after which the theoretical form may be revised to suit the requirements of the practical plant executive. This can only be accomplished by obtaining the soundest criticism and advice from outside sources and incorporating this in our efforts. In fact such simplification has already been accomplished that a graphical chart has been drawn, including all factors except deterioration and obsolescence, from which the value of the economic production quantity may be determined without involving any calculations whatsoever.

[3] General Manager, Bridgeport Brass Co., Bridgeport, Conn. Mem. A.S.M.E.

# Training Minor Executives in a Rapidly Growing Organization

By A. J. BEATTY,[1] MIDDLETOWN, OHIO

*In this paper the author discusses the problem of maintaining a trained working force in the rapidly expanding organization. The problem of the American Rolling Mill Company is used as an illustration of what may be accomplished through proper attention to the requirements of an expanding company and to the material available in the existing personnel. Two courses organized to replace the old Works' School of the company, namely, the Operating Training Course and the Sales Apprentice Course, are described. Other means of meeting new issues in the most effective manner are presented in the author's discussion of the Foremen's Cabinet and the Foremen's Forum, the former serving in an advisory capacity and the latter as an outlet to discussion. A valuable feature of the program of developing minor-executive talent is the Armco Foremen's Bulletin, which has served to stimulate interest in the project throughout the entire organization.*

THE PROBLEM of maintaining a trained working force in a stable organization with a low turnover is a relatively simple one in comparison with that of maintaining a trained force in a rapidly expanding organization. The latter problem has been one of the urgent tasks of the personal-service division of The American Rolling Mill Company during the past five years. During this period the parent plant of the company at Middletown, Ohio, has experienced many important changes and expansions; an entirely new plant, larger than the parent plant, has been built and put into operation at Ashland, Kentucky, and the number of employees has grown from about four thousand to approximately ten thousand, a large percentage of whom, up to five years ago, had never set foot in a steel plant.

The equipment of this new plant is of a new type and design, but it has been brought into production by this almost wholly untrained working force, and has exceeded the anticipated output in quality and quantity. These results have been attained largely as the result of a very specific program of job training.

However, it is not with this job training that this paper is specially concerned, but rather with the development and the training of the necessary supervisory force for this rapidly expanding organization. The situation has demanded new foremen, new department superintendents, and a greatly increased sales force to market the increased production. It is a cardinal point in the policy of the company not to seek on the outside for a man to fill a vacancy so long as there is an available man in its employ ready for promotion.

In carrying out this policy, a large part of the responsibility of preparing men for promotion has been placed upon the training department.

Formerly the company had a training course designed for this purpose, known as the Works' School, in which were enrolled men who were headed either toward minor executive positions in the operating division or toward the sales division. But while this course was quite satisfactory for the sales division, it did not satisfy the operating management because the course was so frequently used by ambitious young operating men, with a leaning toward sales, as a stepping stone to the sales division; and to this extent the course failed to develop men for promotion to more responsible operating positions.

To remedy this defect, two courses were organized to replace the Works' School; one known as the Operating Training Course, and the other, the Sales Apprentice Course. The training of salesmen, however, is a specific story not touched upon in this paper.

In interviewing men who are candidates for the Operating Training Course, the following are some of the questions asked to determine their line of thought:

What is ahead of you on your present job?
What is the next job ahead?
What efforts have you made to fit yourself better for your work?
What study do you need to help you on your job?
Are you prepared to handle a more responsible job just now?
Has any one ever been promoted over you? Why?
What is your idea in applying for this course, and what do you expect to gain by it?
What do you expect to be doing five years from now?
What do you read?
What do you do with your spare time?
How much time are you willing to give to study to master the knowledge of the steel business?

These and other questions usually elicit answers which enable the interviewer to determine how intelligently and how seriously a candidate is considering the necessary means for his own progress. While his schooling is one of the determining factors in enrolling a candidate in the course, his experience and his record are given a good deal more weight than scholarship. Expert ability, knowledge of his job and his department, and ability to handle men are the important factors. Of the men who have taken this course about half have not been high-school graduates, about 25 per cent high-school graduates, and about 25 per cent college graduates. Several have been engineering graduates.

### The Operating Training Course

An outline of the operating training course follows.

*Function.* The function of this course is to provide that special training needed by the students to enable them to succeed to positions of responsibility in the operating division.

*Personnel.* Men are selected for this course by the works manager, or the assistant general superintendents, in cooperation with the superintendents of the departments in which the men work. They are chosen by virtue of such characteristics as ambition, interest, intelligence, health, aggressiveness, and ability to get along with people and adapt themselves to circumstances.

*Course of Study.* The course of study for each student is prescribed by the operating division management and is carried on under the supervision of the training department. When practicable, classes are formed; but in most cases instruction is an individual matter.

The general part of the course, which is required of all students, includes:

*a* Foremanship
*b* Economics
*c* Business law

[1] Director of Training, The American Rolling Mill Co.

Contributed by the Management Division and presented at the Spring Meeting, Pittsburgh, Pa., May 14 to 17, 1928, of The American Society of Mechanical Engineers.

*d* Metallurgy
*e* Business English, and correspondence
*f* Public speaking
*g* Armco products, processes, and policies.

The individual part of the course is determined by two principal factors:

*a* The specific job or department toward which the student is working, and
*b* The student's individual needs as indicated by his previous training and experience.

In the general part of this course, perhaps the most important feature is the study of foremanship with emphasis upon its relation to problems of management. The outline of the course as given in 1926 follows.

*A—The Foreman*

1 The foreman's qualities and traits
2 The foreman's job
3 The foreman as leader
4 Forcefulness
5 The foreman's prestige.

*B—Developing Men*

1 The personal-service division
2 Introducing the new man
3 Team work and cooperation
4 Correcting faults and friction
5 Developing judgment—how we think
6 Developing an understudy.

*C—Problems of Production*

1 Planning work—a daily program or schedule
2 Keeping work moving
3 Keeping up quality
4 Keeping down costs
5 Waste and its cost.

*D—Problems of Management*

1 The foreman as a part of management
(*a*) What is management in industry
2 The foreman's management responsibilities
3 Building good will and loyalty.

*E—What the Foreman Should Know*

1 Company history
2 Why men work—instincts in industry
3 "Levels of intelligence"
4 Company products
5 Company competitors
6 Company customers.

Foremanship is a required subject for men enrolled in the operating training course; for all others it is optional. A new course is outlined and followed each year in order to encourage men to continue this study from year to year.

Each September the first step in organizing for the study of foremanship is to enlist a smaller group of leading foremen—six to ten in number—which is called the Foremen's Cabinet. The men selected for this cabinet are successful foremen, judged by their record of accomplishment in getting work done and in developing men.

The Foremen's Cabinet serves in an advisory capacity to suggest and outline topics for discussion consistent with the above general outline. The Foremen's Cabinet is not a fixed group. Each member is invited to serve for three or four weeks, at the end of which time he may be dropped to make room for another man who is selected to fill his place, generally on the basis of his interest and activity in discussion groups. This plan provides enough holdover men to give a degree of permanence to the cabinet and, at the same time, the addition of new members constantly introduces new blood and new points of view.

The outline for the year being set up, an announcement of the proposed course is sent to all foremen with an invitation to enroll. Those who enroll are grouped into classes of from fifteen to twenty for round-table discussion. This course is open to all who wish to enroll.

The conference method is used. By this is meant that the chairman or leader, while he has in mind just the ground he plans to cover and the conclusions he hopes to reach, undertakes to draw out from the group members the facts and the conclusions so that whatever conclusions are reached are the conclusions of the group. He must also keep the discussion from going too far afield, and lead the group to right conclusions.

This brings up another important function of the Foremen's Cabinet, which is to train picked cabinet members themselves to serve in the capacity of group chairmen, or conference leaders.

Ranking very close in importance with our study of foremanship and management is the study of economics. This is not the study of academic or collegiate economics, but the simple and practical application of this important science. This point is appreciated by the men, as is shown in the following real colloquy reported from the plant:

"Are you in the economics class?"

"Not on your life. My job is to help run a steel plant, not a university."

"Yes, but you have been helping to run this steel plant for fifteen years now, and you have probably noticed that about ten steel plants have been started in this country to every one that is running now and paying dividends; and just about the same percentage of other businesses, grocery stores, restaurants, tire and rubber factories, building and loan associations, and even banks have failed and passed out of existence. Why? Because they didn't look far enough ahead to see what was coming."

The retort of the average foreman to this argument is likely to be, "What's that got to do with economics? That's just good common horse sense."

To which the reply is: "Exactly so, economics is simply the common horse sense which is the basis of all successful business. It is because the management of our company has always done that very thing that our plant has continued to run and allow us to keep our jobs going during the past years when other plants were shut down and their men out of work."

Such discussions as the foregoing are daily occurrences at the plant of the company and in the offices among the men who are attending the economics classes. The company believes that a stable, going business, profitable both to employer and employees, as well as to the community, can be built up only to the extent that all concerned, the employer, the employee, and the public, know, understand, and act upon sound business principles. These business principles which all must recognize and act upon make up what we call the principles of economics.

But it is not enough that the management be students of and informed upon economic laws. The company believes that its stability and growth depend upon the degree to which the entire organization, superintendents, salesmen, foremen, and workers in overalls, are posted on and act upon the economic principles involved in production, marketing, financing, capital, labor, and consumption.

The method of handling our study groups in economics is the same as that outlined above for the foremanship-management groups. Each group has a leader and an assistant leader, these being chosen partly on account of their previous training and

interest in economics, and partly on account of their recognized leadership and stability.

The director of training has a regular weekly meeting of these leaders. Here he presents an outline of the next study topic with discussion-provoking questions. In this group leaders' class are worked out the plans and methods of presenting the various topics.

The leader's job in conducting these classes is not easy. Sometimes the men have not had time to study the lessons adequately; sometimes loquacious members tend to monopolize the discussion, and usually with talk irrelevant to the lesson. Then, too, some leaders are handicapped by a purely pedagogical difficulty in not being skilful questioners.

Most of these groups meet one evening each week on their own time, the sessions lasting from $1^1/_2$ to 2 hours. The courses vary in length as follows:

| | |
|---|---|
| Foremanship, 10 weeks | Metallurgy, 72 weeks |
| Economics, 24 weeks | Business English, 16 weeks |
| Business law, 18 weeks | Public speaking, 16 weeks. |

The instructors are selected from the expert technical men in the organization, most of whom are college and engineering graduates. Some of these men are a little short on pedagogical training, but this deficiency is offset in part by a teachers' bulletin issued by the director of training, and in part by expert and practical knowledge in a specific field. Classes vary in number from three to twenty, the need for the particular class and the students' interest being the determining factor in organizing any class. Textbooks are used in metallurgy, business law, business English, and economics; and lesson assignments are made and reports and recitations are required. In other courses, text material is prepared by the training department in cooperation with instructors.

Another phase of the program for the development of minor executives is a course in company products, processes, and policies. This course is designed to give a complete picture of all departments of the plant and the part each department plays in producing the finished product. Groups taking this course are limited to fifteen to twenty, and one session of the course is given to each of ten departments, including the open hearths, the blooming and bar mill, the hot mills, the processing, the galvanizing, the finishing, the personal-service, the sales, the publicity, and the service-engineering departments.

The sessions in the production division include inspection trips through various departments, followed by discussions led by the superintendents of these departments. The sessions in the non-production departments are each in charge of a representative of that department.

Perhaps the most important part of this training course is the specific training which each man gets in the department in which he is most interested, or in which he is headed for promotion. An arrangement is made with his superintendent so that he is given special attention and opportunity to get all-round experience and knowledge of the department; he makes special studies, and finally writes a report on the department, and submits to a quiz to determine his mastery of the department, the department superintendent and the training department being the inquisitors.

Another means by which the company undertakes to develop executive talent is to keep its foremen posted on business conditions in general, and the company's business in particular. Whenever the management has any important message to get over to the organization relating either to company policies or to business conditions, or to any important change in working conditions, the entire foremen's group is called together in what is called, officially, "The Foremen's Forum."

While occasionally a set address makes up a part of this forum meeting, it is in reality a large group discussion, for it is in every sense a real forum where questions are asked, where discussion is invited, and where explanations are asked for and expected. No important move is ever made by the management in which foremen are vitally concerned and interested without calling together the Foremen's Forum to lay the matter before them, to explain the necessity and the reasons for the move, and to enlist their hearty cooperation in putting it into effect. The result of this plan is that foremen are throughly informed on proposed changes, and can help to put them into operation intelligently; and what is more important, they can explain to their men, in giving their instructions, just why the change or move is necessary. This obviates the danger of any feeling in the minds of the foremen and workers of arbitrariness on the part of the management.

Perhaps the one feature of the program for developing minor-executive talent that reaches the greatest number is the Armco Foremen's Bulletin. This is a one-page, mimeographed bulletin which is issued weekly by the training department and is sent to every foreman of the company and also to every man of higher rank than foreman.

Each bulletin is confined to a single topic of management, or of production, or of organization building, or of economics, or of personal development.

This bulletin is effective in these ways:

1 It serves as a means of carrying important announcements and items of information to foremen.

2 It is an effective forum for the discussion of organization problems, such as: "What Is the Foreman Paid For?" and "Have You an Understudy?"

3 It presents new ideas, or old ones in new garb, to keep the foremen thinking outside and beyond their jobs. "How to Handle the Boss," and "Thinking in Dollars," are examples of this type.

4 It ties in with foremen's group discussions, some bulletins furnishing the topics for discussion, such as "Encouraging Suggestions," and "Why Men Like Their Jobs." Others summarize such discussions as "What is Overhead?" and "How I Get Suggestions from My Men."

The value of the Foremen's Bulletin is suggested by the interest shown in it by foremen and superintendents. Frequently, groups of foremen are found eagerly discussing some point brought out by the bulletin, and at least two superintendents who did not sense its value at the start, and did not keep the bulletins, have since asked for all back numbers.

The one interesting bulletin that brought out a tremendous amount of plant discussion was used about six months ago in which it was assumed that a foreman was giving up his job for a promotion and he was asked to select or to recommend his successor. The employment department selected two men, giving their qualifications and their descriptions, and the foreman was asked to write back in reply to the bulletin which one he would select to take his place and why. They got a great deal and a very interesting discussion out of that.

This paper has elaborated on only the high spots in the program for the development of minor executives and supervisors and the preparation of these men for promotion. The results are, of course, hard to measure; but the best measure seems to be in the men who have moved to positions of greater responsibility through this channel.

## Discussion

R. G. Forbes.[2] The urgent need of training minor executives in our industries is apparent not only to take care of the rapidly

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changing conditions being experienced today, but to prepare for those contingencies that will arise in connection with the revolution of American industry promised us by economists in the not distant future. The writer would suggest a few questions as to the feasibility of a similar plan for industry as a whole in the hope of provoking further discussion by those interested. There are at the present time two ways in which men from the ranks are promoted to minor executive positions. The first is by fitting the job to the man, and the other is by fitting the man for the job through a carefully prepared system of training. The first method is still in common use and usually results in the promotion of a man who is either a close associate of the departmental superintendent, who in turn recommends him to the management, or one who has a record of long and faithful service in the company's employ. In either case very little attention is paid to the fundamental requirements of a succesful foreman. The result is often a barrier that arises between foreman and man that is unsurmountable. The second method is the ideal one, as the prospective foreman is trained to meet the emergencies that arise and is given a close insight into his own responsibilities in such a manner that savors of success.

The important problem of choosing the applicant for the training course has been solved to a great extent by the American Rolling Mill Company, yet nothing is mentioned as to the habit of the prospective applicant in his routine outside the mill. It appears that the industries today are demanding for their leaders men who are also leaders in the civic and social life of their respective communities, and further, men capable of shouldering the problem of home in a commendable manner. If this be true, then the applicant must be judged not only by those characteristics displayed while "on the job" but further by those that portray the manner in which he solves his obligations to his home and his community.

It would be well to include "common sense" to those requirements named in the characteristics of the applicants for the operating training course of the American Rolling Mill Company. It has been said that common sense is the ability to see things in their real light and to deal with them on the basis of sound judgment. Common sense is the monitor necessary to guide a leader out of many difficult situations. It is evident, then, that without common sense the opportunity for the success of the applicant is limited no matter what degree of ambition or aggressiveness he may possess.

The question as to the suitability of holding group meetings on the man's own time or on that of the company has long been discussed, with many arguments on both sides. If the purpose of training these minor executives in a rapidly growing industry be to fit them for their increased responsibilities in the shortest possible time, then every effort should be made to make their training period conducive to the best results that could possibly be obtained. An article appeared some time ago in *Industrial Management* showing a survey that had been made in several industrial plants concerning the efficiency of the men during the various hours of the day and night. The results pointed out conclusively that the best work was done in the morning between the hours of nine and eleven. From another source comes the information that a survey of the various colleges and universities showed that the students did their best work of the day in the morning between the hours of eight and eleven. A class in economics was held some time ago at the Ellwood works of the National Tube Company. The class convened at five-thirty in the evening. Although a standard textbook was used and the class was led by a competent instructor, yet the class terminated with but a fair measure of success, owing in large measure to a natural physical and mental reaction that set in after a hard day's work was done. It would seem, then, that the most advantageous plan would be to conduct all classes during the morning, rather than either in the afternoon or evening, and on company time, since it is evident that the compnay is more interested in developing minor executives than it is in the quantity of production of any individual during his training period.

The problem of planning the curriculum of any training course is a most important one. It would not be expected that the textile industry would include the same courses of study as the steel industry. However, there are two courses that are of basic importance in the development of any operating training course, namely, foremanship and economics. Although in some plants the phrase "minor executives" is used to include department superintendents, yet literally it embraces only foremen and sub-foremen. If this be correct it is only natural to expect that the course in foreman training be emphasized more than any other and that a greater part of the training period be utilized by this subject. In a course in salesmanship the subjects of business English and public speaking are valuable, but in an operating training course the inclusion of these subjects in the extensive manner that the American Rolling Mill Company suggests is a matter of some conjecture, as a necessary requisite for a successful foreman is his ability to converse with his men in the language of the mill and that does not necessitate the outlay of time and expense in developing complete courses in either business English or public speaking.

The effective use of the bulletin service in reaching the foremen and sub-foremen is commendable. How many of our minor executives are today going about their duties unconscious of the problems of management in which they should be vitally interested. It is quite possible to develop successful foremen, but once the foreman has passed on to his new position the problem of keeping him mentally alert and interested in his job presents itself. This can be made possible by the suggestion of problems of management, up-to-date topics of mutual interest to all foremen, and the presentation of new ideas that will give him the opportunity to enter a discussion with his fellow-foremen or his superintendent. This can be accomplished through the medium of a well-developed bulletin service.

Therefore in the planning of an operating training course for minor executives three primary factors are included; namely, the careful selection of applicants for the course, the contents of the curriculum, and the most advantageous time for conducting the classes both from the standpoint of the management and the student. Whether the development of these points by the American Rolling Mill Company presents the ideal solution can only be determined by individual considerations.

C. S. Coler.[3] This question of finding and developing men who can be executives is quite an important one in industry. It seems to the speaker that executive work requires three things: first, length of vision; second, breadth of information and experience, and third, depth of understanding of human nature.

The program which the author has outlined seems to be well calculated to develop these three things in the individual who is going to be a leader. In our modern organizations the executive is more and more becoming a professional man. He is the universal joint between capital and labor in one direction, between the seller of raw materials and the buyer of finished product in another, and between his own organization and the public at large in a third direction. The training of minor executives is primarily an executive function and secondarily an educational function. We are dealing with mature men who have a background and who have a certain standing to maintain in the eyes of their workmen.

[3] Manager, Educational Department, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

In our own organization our works manager selected a group of ten supervisors and worked out with them in a series of conferences a definite program of procedure for meetings which were intended to develop executive ability. Later on each of these ten men was put in as the secretary of another group of ten men, thereby bringing together ninety supervisors in the second group. They in turn worked out programs for each group intended to develop those individuals.

Some of the subjects that were covered are: The characteristics of a good supervisor, duties and responsibilities of a foreman, duties and responsibilities of a cost man, duties and responsibilities of a rate man, duties and responsibilities of an inspector, the new employee, measuring and grading employees, the problem of wages, building up and maintaining a working force, safety, control of work in process of manufacture, transportation, handling of materials, quality production, control of defective work, service department, suggestion system, and factory costs.

No standard texts were used in connection with this work, but the men used many sources of information in gathering the material, and as a result of their activities have published several pamphlets dealing with the subjects they discussed.

The older method of creating executives was fundamentally a method of sink or swim. It was competition from the word go, and survival of the fittest. In those days organizations were small, and each individual secured a sufficient variety of experience to give him the background that he needed. The individual grew as the organization grew, and oftentimes executive work was given as a reward for high-grade work in some technical line.

New conditions have brought in a longer school period, specialized jobs, a lowered discipline and urge on the part of the individual as a result of prosperity. The larger organization makes the top seem farther away for the new and younger man. And the executive has become a hired man instead of the man who owns the business.

Present methods of training have had to take these things into consideration. We are finding today that the first step is a very careful selection of men coming into the plant, so that we will have a sufficient amount of inherent executive ability in the organization to draw on in filling vacancies; then we must keep careful records and conduct reviews from time to time to detect special executive ability; finally, we should institute training courses, such as those outlined by the author, to broaden the experience of the individual.

We find that it is advisable in developing executives to start giving responsibility to men just as early as possible. The acceptance of responsibility, in fact, is the keynote of executive development.

We have been trying to build into the Westinghouse organization a substantial background for promotion into executive work through our trades training, intermediate training, and graduate student courses. The idea back of all of these courses is to give the men a broad conception of the problems involved in our organization, the products and policies of the company, and our personnel. It is a movement that is intended to counteract the effects of the movement which has been going on in the direction of more highly specialized jobs.

R. L. Kirk.[4] The company that the writer represents, being a public-utility company, does not produce in the sense that most of you do in turning out some tangible commodity. We do not have quite as many foremen, perhaps, and we may have more technical men in our organization in proportion to many of you, so that the problem of training minor executives is perhaps not as important as training the men a little higher up. I think that there is plenty of executive material around; in fact, any of you men that have had anything to do with the young boys think that all they want is to be executives, to get into the management end of the business.

The writer believes that a certain amount of luck enters into the selection of a young man or the reaching of a certain height by an executive. Suppose that in any organization you take the president away and put a new president in his place, and how many of the same staff would he select?

We have a systematic personnel department headed by a director of personnel. It seems to the writer that one of the most important things about the seeking and training of executives is to have a sympathetic attitude. Some executives carry all the burden on their own shoulders and will not let any of their subordinates do a thing. Other types of executives push it all on the subordinates and tell them to "sink or swim." The executive has to get the habit, he has to get the thought, he has to try these young fellows out. Give him an opportunity to be an executive. The Duquesne Light Company has several means of training minor executives. We operate an apprentice engineering course, in which we take men directly from college, put them through a twelve months' training period and let them seek their own level. We have departmental courses where we take college and non-college men and put them through courses in their own particular departments. We have a very liberal transfer policy. Many men come into our organization in a certain line of work where they are better fitted for other types of work, so frequently we transfer people from one department to another in trying to fit them in.

We have cooperative schools working with the university and high schools, and the trade schools, where a boy goes to school for two weeks, comes into our company and works for two weeks, goes back to school for two weeks more, etc. thereby getting our point of view and the training at the same time.

We have various types of schools in the organization. One of the steps we took last year was to organize an economic or general administrative course of economics which was open to all the members of the company. We enlarged that and made it a class for utility administration. We had 70 men enrolled there. The junior executives, the president, vice-presidents, general attorney etc. met with these men and told them their problems, a kind of an open forum. On Saturday mornings we have started something in the way of general sales classes. Our regular starting hour for work is eight-thirty. We begin these classes at eight o'clock and carry on until nine, so that half is on the company's time and half on the employee's time. We have had such a response that we do not have a large enough hall and we are putting up a building for the purpose.

Much of our training is given through the night-school work. We emphasize public speaking, and we have six or seven public-speaking classes and five or six economics classes. We have the Wranglers Group, whereby men of the same type get together and argue back and forth, so to speak.

We have the Contact Club, of about three hundred senior and minor executives, that meets once a month to discuss ways and means of doing a thing better. Last of all is the suggestion contest, and we get a lot of good suggestions. Many persons have been promoted to responsible positions because they have come before the management through suggestion contests.

J. O. Keller.[5] What a large company can do for its own supervisory personnel, The Pennsylvania State College, through

[4] Assistant to System Development Engineer, Duquesne Light Co., Pittsburgh, Pa.

[5] Head, Department of Engineering Extension, The Pennsylvania State College, State College, Pa.

its Department of Engineering Extension, has been doing for some of the smaller organizations of this Commonwealth that do not want to spend the money for a special training force. Moreover, some of the larger industrial organizations of the State that easily could afford to set up their own training organizations have also been using this special training service.

Secretary of Labor James J. Davis, in the January, 1928, issue of *Current History*, has very aptly described the conference method as follows:

"This method is based upon the idea that an experienced foreman will profit most by a supervised discussion of his problems with a group of experienced foremen. This discussion is carried on under the leadership of a chairman or conference leader who does not necessarily need to know anything of the details of the foreman's job. His principal function is to aid in the discussion by helping the foremen to organize their ideas, to analyze situations, and also to hold down discussions to the point. He acts more as a general chairman than as a teacher. This plan has extended itself rapidly during the past two years with splendid results."

Our first experience in conference training was in the last year. It has been accepted so enthusiastically by various industries that in addition to the special conference leader employed to inaugurate the work two additional men had to be secured to meet the demand.

During the past two years we have conducted 37 conference groups, all of them with excellent results, in the following types of industries:

| | |
|---|---|
| 1 Structural steel | 14 Machine tools |
| 2 Steel sash | 15 Textile machinery |
| 3 Tool steels | 16 Yarns |
| 4 Small tools | 17 Broad silk |
| 5 Saws | 18 Other textiles |
| 6 Machine shop | 19 Paper cups |
| 7 Foundry | 20 Rubber tires and tennis balls |
| 8 Forgings | 21 Cork and insulation products |
| 9 Non-ferrous metals | 22 Linoleum |
| 10 Automobile bodies | 23 Zinc |
| 11 Automobile trucks | 24 Paint |
| 12 Pressed metal | 25 Chemicals |
| 13 Ice machinery | 26 Safety appliances |

The growing popularity of the conference method is quite evident, for since we started supervisory training in 1922 we have had in addition to these 37 conference groups 68 groups of other types of foreman training.

We try to have 12 men rather than 15 to 20 in a group, although we have taken as low a number as 10 men and as high as 16. We are led to believe, however, that 12 is the ideal size for the conference leader to get the best results.

The mechanics of the conference are very important. We insist upon having the men group themselves around a long table, an arrangement which makes them feel more at ease and they are more willing to "open up" and take part in the discussion. If a table is not used, the men necessarily face each other, and they feel ill at ease, are conscious of their legs and hands, and tend to keep silent. Then a blackboard at the end of the table near the conference leader or a folio of large sheets of paper which may be torn off as they are used enables the leader to illustrate many points, draw pictures or cartoons, and list the points of the discussion as they come out of the group.

Not all men are conference leaders. We have tried to train many of our staff to act as conference leaders, but only one man out of about eighteen may be considered good enough to handle industrial groups; and then this one man must be given special training under other good leaders for about one year before he is prepared to conduct conferences in a manner that we consider a quality job. We have found that better results are secured where the conference leader has a practical background, not only in actual handling of men, but also in knowing something of the problems of the particular industry in which the training is conducted.

The success of our conference training may be principally accounted for by the care and attention with which we select our conference leaders. This careful selection may not be so essential in an organization in which the method does not have to be "sold" to an outsider; but in our work, where every small as well as large firm must be thoroughly convinced of the merit of the proposition, we have to consider seriously and carefully the selection of our conference leaders. The burden of obtaining the cooperation of the management as well as "winning over" the supervisors who are to take part in the conference, both essential to effectiveness, rests largely on the conference leader. The initial persuasion is effected by means of a demonstration conference. The conference leader must do a high-quality job on this occasion, even if the conditions are unfavorable to "put over" the conference training idea.

From all indications we expect to have our biggest year starting next fall, and already we have had requests for conferences which will keep our three men constantly busy. Other firms are indicating their desire to begin the work as soon as we can give them the time of a conference leader.

A rather interesting peculiarity about "selling" conferences is the fact that whoever gives the satisfactory demonstration is always requested by the firm to conduct the entire program. The firm usually believes that we have used our best man to demonstrate and then expect to switch to some poorer man for the actual work. We have therefore always made it a point to demonstrate with the man that we expect to use in that particular territory.

Some of the results of this method with the plants where we have done this work can be summed up under the following items:

1 Continued high interest.
2 Content matter readily absorbed.
3 Retention of the knowledge gained.
4 Assurance of the application of this knowledge to the job.
5 Development of analytical ability.
6 Development of ability to weigh facts.
7 Development of a common understanding among the foremen and other plant executives.
8 Assurance of the practicability of the content matter to the extent that it will result in ultimate cost reduction.

Arthur Williams.[6] The writer feels that the question of building a reserve force and having department heads train those under them to take their place is one of the greatest importance. The points the author has made about diversified training and the idea of discussing matters in groups also appeal to me as being finely thought out.

In the early days we leaned largely to the idea of the "born" salesman, but the supply soon gave out. In any event it is only by such thorough training as suggested by the author that the representative, whether salesman or not, can leave a lasting and convincing impression upon the customer. It oftentimes means the difference between a good opinion on the part of the latter or a bad one. Perhaps most important of all, training and procedure along the lines suggested do much to enhance among the employees that most essential of qualities, sound judgment.

[6] Vice-President, Commercial Relations, The New York Edison Co., New York, N. Y. Mem. A.S.M.E.

John D. Beatty.[7] It seems to the writer that in the smaller towns, such as Middletown, where there are one or two large manufacturing companies, the companies perform nearly all of the educational functions, while in Pittsburgh and other large communities we find that the universities and public schools are doing a great deal of the training.

We have at the Carnegie Institute of Technology 4000 night-school students who are acquiring valuable technical education for a nominal fee. The majority of these men come from about 30 of the leading firms in the Pittsburgh district. The Westinghouse Company alone has over 400 men taking vocational courses. A startling fact discovered upon registration of these 4000 students was that 11 per cent were unemployed owing to a slacking of the industries in the district. The employees' desire for an education continued, and I am glad to say that all the good men in that 11 per cent have been re-employed by the companies forced temporarily to lay them off or have been employed by another company in the same line.

Another fact discovered during the recent slowing up of business was that the college graduates held their jobs. Of this group we noticed that $^1/_{10}$ of 1 per cent were out of work in any one month as compared with 11 per cent of the non-college group.

You have been talking about foremen, men who are not educated, but industry today is demanding college men, and the colleges are becoming a testing ground not only for big executives but also for the minor executives. They say it takes 20 years to become an executive. Four years in college gives a good test of what a man will do. A recent study at the Carnegie Institute of Technology showed that the men who had a high scholarship rating and high activity rating, a good personality as we might say, were the most successful after they were graduated from school. They earned the most money and had the best positions.

All the technical schools and universities have been trying to persuade the industries that scholarship is a measure of a man's capabilities in the business world. A recent article entitled, "Does Business Want Scholars?" by W. S. Gifford, president of the American Telephone and Telegraph Company, published in *Harper's Magazine*, May, 1928, substantiates this theory.

Orlan W. Boston.[8] The author stated that 25 per cent of the students enrolled in these courses were high-school graduates and another 25 per cent were college graduates. I should like to ask if the additional four years of training in college is manifest in the results that are obtained through this foremanship or managerial course.

The writer, although interested in, has not been directly active in the matter of training for industries for eight years, but was for two years following the war. During that time Dr. Howe, president of the Case Scientific School, called a meeting of representatives of about 60 Cleveland industries to determine what the industries expected in college graduates at the time of their employment. I happened to represent one of these industries. It was interesting to learn that the majority present favored an engineering graduate who had been given a general training, that is, one who was well versed in English, perhaps a little public speaking, economics, and the fundamental subjects of chemistry, physics, and mathematics, rather than one who had specialized in any line of engineering work. It seems then that training for industries can be divided into two main phases: one is the college training needed by the industry, and secondly the subsequent training by the industry for the positions to be filled.

[7] Secretary, Bureau of Recommendations, Carnegie Institute of Technology, Pittsburgh, Pa.

[8] Professor of Shop Practice, University of Michigan, Ann Arbor, Mich. Mem. A.S.M.E.

I once started a statistical department in an industrial plant as a part of a program to reduce costs. I charted certain accounting-department records and mounted the charts on the wall of my office so they could be observed and studied by the employees and supervisors. Information was presented, such as attendance and lateness; costs of unit parts, such as sub-assemblies and final assemblies; departmental expenses; general costs, such as direct labor, direct material, overhead expenses, administrative expenses, and selling expenses; and cost of scrapped material. The foremen and other supervisors soon became interested in these charts, as well as in the general welfare of the company. Many additional subjects pertaining to shop practice were discussed. It was evident that by giving these administrators of various departments and divisions information pertaining to their work they were better able to direct and control their work.

I wonder if in the course of training illustrated by the author it included such items as costs; that is, if the items that enter into the cost of parts being made in that plant, such as direct labor, direct material, overhead, and so on, were given to the workmen or whether hypothetical cases were used. It seems to the writer that it is very desirable that the foremen and superintendents be given information regarding the particular industry. I think that the quickest way to gain their confidence is to make them feel that they are a part of the organization, although I know of some companies that resent that attitude.

C. P. Morrey.[9] One question has bothered our organization to some extent. We have conducted a part-time training course, apprenticeship, and on the completion of this course we aim to train the men for foremen's positions; but we found that, with the exception of one student, these men on completing their training have entered college, taking them entirely out of the field of the assistant foreman's or foreman's position, and going elsewhere for work. Also when men have been trained, has there been any difficulty in placing them in more responsible positions, and if openings are not available, do those men get uneasy and look elsewhere for work?

W. T. Magruder.[10] We know that the majority of engineering college graduates become supervisors and executives in the course of time. Their post-graduate training should therefore be with this objective ever before them. As to what may be done to help the graduate, my first answer is that he should be induced to become a member of The American Society of Mechanical Engineers, or the kindred society of whatever industry he enters. A year ago I tried to get the Council to see what could be done relative to getting a larger number of our M.E. or B.S. graduates in mechanical engineering to become members of this Society, as I was surprised to find that only from 8 to 38 per cent of those graduated in mechanical engineering are members. The same is probably true of the other professional engineering societies.

Second, he should be made interested in the work of that society. The trouble seems to be that too many of our graduates are thinking of their education as that of a trade education rather than as a professional education. The idea is, "Oh, I have my education. What more do I want?" Commencement Day is for some a "Terminus Day," educationally.

Third, they should be permitted and urged to attend local, regional, and professional meetings of their society and required to read some of the papers in which they should be interested.

Fourth, the young graduate who expects to rise and become

[9] Rhode Island Coal Co., Providence, R. I.

[10] Professor Mechanical Engineering, Ohio State University, Columbus, Ohio. Mem. A.S.M.E.

a minor executive should subscribe to at least two technical magazines in their present and desired line of work, and should read them, and thereby keep up their interest in some one branch of the profession. If they can be induced to subscribe and pay for a technical magazine, they are more likely to read it. The next best practice is for the company to subscribe to several magazines and assign to different men who would be benefited there by the reading and abstracting on the company's time of articles which should be helpful to the company.

Fifth, the young graduate and all executives should be expected to be interested and take part in some of the civic, social, charitable, religious, and recreational activities of the community, and so be a human being and a man as well as an engineer.

The author said that you never produce executives except by letting the executive produce himself. When you have the opportunity to let a man have a little chance to show his ability, as for example when a foreman is sick or on vacation, then you will find out whether a man has initiative and stamina, and if he is able to lead. You may give him a chance for two weeks in the summer-time when it is hot and the gang foreman is away. Does he run away with the job or does he let it run away with him? Does he rattle around or actually do something worth while? You can watch him and see what he does know and can do. You have to train your executives by letting them train themselves; but the way to train them is to give them a chance.

# Systems of Workman Payment in Porcelain Factories

By HOBART M. KRANER,[1] EAST PITTSBURGH, PA

*This paper describes the application of Standard Time and several other incentive systems as applied specifically to an electric porcelain plant. It points out the necessity of detailed study of the various operations in determining the applicability of the systems to these operations. It also points out the disadvantages of the simple piece-work system so much used in porcelain plants where Standard Time and other such wage-payment plans have not been studied.*

IT IS NOT the purpose of this paper to describe applications of various wage-payment plans, but to give a description of methods which are being applied in the operation of insulator plants.

The straight piece-work plan in which the workman obtains a uniform price per piece is the one generally used as an incentive for greater output in ceramic plants. The reasons for this system being used so extensively are probably that (1) the size of the organization does not warrant employment of personnel particularly well acquainted with other information along such lines, and (2) that a simple piece-work system makes calculation of the wage due the man relatively easy. Such straight piece work has the disadvantage to the workman of severely penalizing him for things often not within his control. It is impossible for a new man or one using a defective tool or die to make a reasonable wage. In the latter case it may be one of the unforeseen difficulties encountered in manufacturing. Obviously, neither of these men should be penalized by smaller wages due to these causes. Although piece work does stabilize costs and simplify calculation for the cost and payroll clerks, it is unfair to the workman.

In some porcelain plants, particularly those making dry-press porcelain, it would be difficult to form many pieces by straight piece work due to the fact that the orders are small and it would be difficult for the workman to develop technique sufficient to warrant establishing a piece-work price on certain jobs.

In one dry-press porcelain plant the management has abolished piece work entirely. They do, however, keep accurate production records and have a thorough knowledge of fair daily production on all standard pieces made. The quality of the man is subject to periodical grading according to his production records. This has the effect of giving the man fair treatment on days when he may not be feeling 100 per cent efficient or when, for reasons not within his control, he may be unable to produce an amount representative of his ability.

It is becoming more general to recognize the necessity of establishing a minimum wage whereby the workman can be assured of a minimum figure for his day's effort. An incentive for greater effort is also to be desired. Many such plans have been devised.[2]

Standard Time is an incentive system which has for a long time been satisfactorily applied to operations in large industrial plants and is now being applied with equally good results in porcelain-insulator manufacture. It is believed that the success with which this is being used warrants a description of the application.

Standard Time operates as follows:

1 All operations of a job are classified or evaluated. This establishes the quality of man required on the operation.

2 The Standard Time is the time allotted the man to produce 100 pieces on his operation. This is established by time study or experience.

3 If for any reason the man fails to meet his Standard Time he is not penalized and receives his guaranteed hourly rate. Continual failure, however, will attract investigation.

4 If the man meets his Standard Time he receives an increased hourly rate of approximately 10 per cent on his entire day's production.

The successful application of piece work or any other incentive plan such as Standard Time will depend upon:

1 Standardized methods of production
2 Sufficient production to warrant such a system.

Porcelain plants are not sufficiently perfect in these to permit a full introduction of Standard Time, as the accompanying flow sheets will indicate. The description of the application also indicates how far this plan can be introduced in porcelain manufacture.

## Plastic-Process Porcelain

*Raw Materials.* The unloading of raw materials is often influenced by non-uniformity of the clays received, whether wet or frozen, etc., and by difficulties in having cars placed properly. These conditions may affect the satisfactory application of an incentive system. The predominance of materials such as china clay, flint, and feldspar which are easily unloaded by hand methods or by the assistance of conveyor systems makes it possible to apply such systems to unloading of raw materials very satisfactorily.

*Body Preparation.* Probably the most critical of operations in a porcelain plant is the weighing of the mix. This should not be placed on any incentive system. Ball milling and blunging are operations which are governed by the time required for the equipment to prepare the material. Since this is not within the power of the men to change, these operations cannot be put on any but day work. Filter pressing, pugging, and mauling into aging cellars are readily paid Standard Time.

Pugging the aged clay into blanks for subsequent operations is another critical operation which requires the unlimited time of the men to obtain uniformity of product. This, therefore, should be done by day work.

The forming and subsequent operations of high-tension-insulator manufacture are well standardized, and Standard Time is readily applied to the hot pressing, trimming, glazing, and sanding operations. Most of these operations are done in groups or gangs in which a number of men apply their efforts simultaneously on the several parts of the major operation. For instance, in hot pressing there are mold fillers and mold runners as well as the pressmen. Each receives an individual hourly rate depending upon his work in the gang.

Placing of ware in kilns, whether this be into periodic or tunnel

[1] Ceramic Engineer, Westinghouse Elec. & Mfg. Co.

[2] "Industrial Organization," Kimball, American Management Association, 1925.

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kilns, is always a subject of serious consideration. Firing is approximately 30 per cent of the manufacturing cost, and it is essential that the kilns be filled as full as is practicable. Some inducement must be offered the men to utilize all the space that is available. Some plants give each of their shapes a unit value based upon their overall cubical contents, and to establish incentives for compact filling of the kiln. This method is practically identical with another which is used perhaps even more generally, in which the actual cubical content of the piece is indicated in cubic inches. The placing efficiency is then indicated in cubic inches. By so doing the men will place small pieces of ware in and around larger pieces or in other hollow pieces, thereby utilizing the kiln space to the fullest extent.

The same methods may be readily applied to the loading of tunnel-kiln cars. Here it is a matter of greater importance to the safety of the kiln and ware, however. The choice of first-class saggers and lack of painstaking placing of ware may result disastrously. It may therefore be inadvisable to place tunnel-kiln operation on any incentive plan which would appear to reduce costs unless the management can be assured of eternal vigilance on the part of the foremen in safely loading the cars to stand the trip through the kiln.

Drawing of ware is easily placed on an incentive basis. In periodic-kiln practice the kilns will average so nearly the same in quantity placed on the cubical-content or unit method that the kiln may be used as the drawing unit. Drawing as well as placing is usually a gang operation, and includes delivery of ware to the inspection department. Inspection is usually regarded as part of the firing operation and is, of course, day work.

*Dry-Pressed Ware.* The mixture for dry-pressing porcelain is prepared the same as the plastic-process material, except that the filter cakes are allowed to dry and are then pulverized. It is quite convenient to set rates on dry pressing, and this department is very readily placed on Standard Time. Furthermore, it is possible to place dry-press clay preparation on a basis whereby the cost of clay preparation is standardized. The men pulverizing and screening the clay can operate as a group and be paid in proportion to the presser's output. Trimming and glazing of dry-pressed ware are likewise logically paid by Standard Time.

*Cast Ware.* Preparation of the body for casting bushings, etc., for high-voltage use consists of weighing, ball milling, and screening. As stated before, such operations should be paid for as day work.

The making or casting operation requires that the caster work on so many different styles at the same time that it is difficult to place a rate on the respective styles in this operation. This would not be true in casting plants where one man makes only one style of piece as is done in sanitary-ware plants.

Trimming or turning of cast ware is, however, very readily placed on Standard Time for, although a man may work on a number of different-style pieces in his day, the time required for each is definitely obtained. Difficulties encountered in glazing, and care required in time handling of large cast insulators, make it inadvisable to place glazing of such large pieces on anything but day work.

### Saggers

The sagger departments of most ceramic plants are very adaptable to incentive-plan payment of labor. The preparation and making may be operated in group system. This has gone in some plants even so far as to pay men only for the dried perfect saggers upon their delivery to the placing foreman. This puts the responsibility of drying in the hands of the sagger-shop men.

### Crate Making and Packing

Packing is done in crates, thin boxes, and special thin wirewood boxes. Crates and boxes are each made by machine in several operations. Each operation is paid by Standard Time. Packing is likewise paid by Standard Time.

### Shop-Production and Loss Records

Such records are of vital importance to the cost department. In a department where sufficient ware passes to make it economical, it is most satisfactory to employ a clerk to obtain these data. Foremen in the smaller departments must be relied upon to turn in proper records by checking up on the pieces made by their men and reporting losses at each operation. Loss reports are necessary in order to obtain accurate cost data. It has been found that by pointing out discrepancies between numbers produced and losses from operation to operation, the figures given to the cost department are kept fairly accurate. For instance, if a dry presser pressed 1000 pieces and a trimmer reported 1100 trimmed, the discrepancy would be apparent. The cost department therefore has a check on the foreman on the small orders, but the overlapping of quantities in the various operations on the styles being made in large quantities makes such a check impossible there. Fortunately such larger production will bear

### FLOW SHEET

#### Plastic-Process Porcelain Manufacture

Raw-Material Unloading
Body Preparation
- Weighing
- Blunging
- Ball Milling

Filter Pressing
Pugging and Storing
Pugging (blank cutting)

| Suspension and Multi-Part Pin-Type Insulator | Tubes | Jiggered Ware |
|---|---|---|
| Hot pressing | Turning | Jiggering |
| Mold filling | | |
| Mold running | | Trimming |
| Dumping from molds | Drying | |
| Ware carrying | | Drying |
| Trimming | | |
| Ware carrying | Glazing | Glazing |
| Drying | | |
| Glazing, sanding and ware carrying | | |
| Placing and ware carrying | Placing | Placing |
| Firing | | |
| Drawing | Drawing | Drawing |
| Inspecting | | |
| Testing | Inspecting | Inspecting |
| Assembly | | |
| Spraying | Testing | Testing |
| Cementing | | |
| Cleaning | | |
| Testing | | |
| Packing | Packing | Packing |

#### Flow Sheet — Dry-Pressed Porcelain

Body Preparation
- Crushing filter cakes
- Pulverizing
- Screening

Pressing
Trimming
Glazing
Placing
Firing
Inspecting
Packing

#### Flow Sheet — Cast Porcelain

Body Preparation
- Weighing
- Ball milling

Casting
Drying
Turning
Glazing
Placing
Firing
Inspecting
Packing

the expense of such clerical help, and this is of course the most satisfactory.

### Conclusion

It has been shown by the foregoing that a modern incentive payment plan can be applied to the manufacture of a wide variety of porcelain pieces. The methods described are not as yet perfected and are undergoing constant study to eliminate day work and piece work in an effort to not only reduce costs but to obtain accurate cost data.

## Discussion

Robert F. Ferguson.[3] This method is very similar to one which is fairly well established in the making of firebrick. In the firebrick industry a certain number of bricks is counted as a day's work. Whenever that number of bricks has been made, the men go home. If they make more, they get paid for more than a day's work. Take, for instance, a hand molder. If he should mold 800, he gets one and one-third pay. If he molds 600, he gets the full-day pay. If he molds his number of bricks by noon, he can go home. The firebrick plants are rather small and are pretty well under the control of one superintendent, which might make it easier than in a big plant, but this system prevails practically throughout all plants, and very few men work straight hours. In the case of hand molding, the number of bricks that the hand molder gets out and that pass the inspector sets the day's wages for everybody connected with the hand-molding department. The hand molder's rate will determine the wage for the carry-off boys and the men drying the mud and the men that wheel the clay; it is all based on the number of bricks he gets out. The only thing this is tallied is the day's production and that has to be turned in anyway. And from the number of bricks that the hand molder gets out, the wages of the clay wheelers, pan tenders, mud wheelers, and carry-off boys will all be fixed.

In setting the green brick, the number of bricks determines the wages for the green-brick wheelers and laborers connected with setting. In the case of setting intricate shapes which require care and where there is apt to be a loss to the man, a rather unique system prevails in Pennsylvania plants. The one crew will be working on the brick and several other men will be working on the shapes. There will be no time kept at all of the number of special shapes. They will divide up, and one crew will work on standard bricks and the other crew on the intricate shapes, and whatever the crew makes on the standard bricks will be paid to the crew on intricate shapes.

In wheeling burned brick a standard number of brick is the basis for a day's work. Whenever a certain number is wheeled the workmen are through. Everything is based on the 9-in. firebrick, and there is an adjustment figure for specialties. For instance, if a molder is supposed to make six hundred 9-in. firebrick, in complicated shape he might only have to make 400 equivalents, or if it is very intricate, 200 equivalents. Rates for these conditions have to be established, and are not established on the number per day, but on the basis of the 9-in. equivalents supposed to be counted for a day's work.

The same system is followed throughout the kiln firing. A man is supposed to be paid on the basis of 12 hours' time for firing a hot kiln. If the kiln is in the preliminary stages, he is credited with half-time. In other words, if he is in charge of only one fresh kiln he gets 6 hours' pay for doing 12 hours' work. If he has one hot kiln, he may get 18 hours' for 12 hours' work. If he happens to have two hot kilns, he may get 24 hours' pay for 12 hours' work. The same system is followed all the way through the manufacturing process from the green mud to the burned brick. It seems rather complicated, but when understood, it is admittedly a rather fair method.

In machine work it is not quite so easy to apply this method because there are always difficulties such as breakdowns, loss of power, belt slippage, and "galloping the goose" as we call it, which is running the clay out of the augers and back into the pug in circles. Things like that are bound to happen, so it is not easy to apply the method in a machine plant. But it is done by setting a limit fairly low so that the men can finish their day's work by three o'clock, and then, if everything goes all right and they work until four, they get more than a day's pay. We make plenty of allowances for things beyond the men's control.

There is very seldom any misunderstanding with the management and the men working close together. The firebrick industry in Pennsylvania is old, and traditions have been worked out and precedents have been established so that there are not so many questions as would seem on the surface of it. The writer thought it might be of interest to know that the author's system was not unique; but that it is one which has been pretty well established in the Pennsylvania firebrick industry.

J. B. Blewett.[4] The system that seems to appeal to some branches of the refractories work is to establish a certain amount of work with no practical limit. That is, within 10 per cent variation, a man wheels 8000 bricks for a day's work. He would not be permitted to run 8500 and he would not be permitted to work more than eight and a half or nine hours, or whatever his hours are. The object is to keep up the quality of the man's work, and to hold him to a set standard rate, and not to make it possible for him to hurry and get so much done that he can get home at noon.

P. D. Helser.[5] The author's discussion of the different systems of wage payment being used by the various porcelain factories is, indeed, very interesting. The Standard-Time system certainly has considerable merit. It would appear, however, to be more readily applicable to some branches of the ceramic industry than to others.

A large percentage of high-voltage insulators, for example, are formed by the hot-press method, which is a mechanical operation, whereas vitreous sanitary ware is made almost entirely by the casting process, which not only is a hand operation but requires considerable craftsmanship. Furthermore, in the casting process, as in all hand operations, the personal factor is involved to a very large extent. It is undoubtedly possible, however, to use the Standard-Time system in the ceramic industry much more widely than it is being used at present.

A number of the vitreous sanitary-ware manufacturers are at present using the straight piecework system of wage payment. The base rate is established by taking into consideration the skill required to make the piece, the finishing required, the weight of the piece, the conditions under which the work is done, the number of pieces that constitute an average day's work and an adequate daily compensation for the service rendered. For example, the fair rate on one piece may be 70 cents. If ten pieces are made per day the total daily wage would be $7. If, however, the pieces are very large and require considerable work and skill, a total daily wage of $9 might be warranted. If it is possible to make only three pieces per day, the rate would obviously be $3 per piece.

Some of the larger sanitary-ware manufacturers use a wage-incentive plan commonly known as the bonus system in con-

[3] Mellon Institute, Pittsburgh, Pa.

[4] McLaine Firebrick Company, Wellsville, Ohio.

[5] Eljer Company, Ford City, Pa.

nection with the regular piecework system. While it varies somewhat in detail and application at the different plants, it is essentially the same. Each piece of ware is marked permanently with the number or initials of the workman and the date made. If a workman has no loss for a period of one month he is paid a total of 10 per cent of his total earnings for that period. If he loses one piece, he is paid a bonus of 8 per cent; two pieces, 6 per cent; three pieces, 4 per cent; four pieces, 2 per cent; and five pieces or more pieces, no bonus. One company has a bonus period of two weeks instead of one month. The ware is checked through the bisque kiln or first fire and all losses for which the workmen are responsible are charged back to the men on the regular making-price basis. If there are any losses in the glost kiln or in the finished-ware stock that are obviously due to poor workmanship these also are charged back to the men. A given sum of approximately $25 is retained from each man's pay against which all of his losses are charged.

One disadvantage to this wage-incentive plan is that the men are likely to conceal defects in an effort to have no losses charged against them. Such defects may not be found until the ware is placed in service. However, the various companies that are using this plan, as well as the workmen, appear to be well satisfied with it.

W. Keith McAfee.[6] The ceramic industry is very different from a great many industries inasmuch as it is empirical; there is practically no technical control in the same sense as in most other industries. For instance, take the problem in the casting shop. So far as the writer knows, we all pay piecework, so much a piece for casting, and at the same time fix a minimum of eight hours. We tell the man that he can make only 10 or 11, depending on the particular method. In other words, there is no incentive except to make the allotted number and pass the inspection given them. The reason is simply, as has been pointed out, that the man can gloss over defects before the ware is put into the kiln, so that if the green inspector can find these defects, the loss will not be as great as if the ware had gone through the kiln. Consequently, if the barriers are taken down and a wage-incentive or a speed-incentive scheme is adopted, there will be a lot of defective ware coming out of the kiln, because the man will take a chance and patch it up and it will not be caught in the inspection, since the man can do some things to it that cannot be detected and that do not show up. It may even be something that will cause the piece to break open in the kiln. Of course, the same conditions exist in all other branches of the ceramic industry.

For that reason any wage-incentive scheme must also have a factor in it that is governed by performance. In other words, the writer personally would hesitate to put in Standard Time unless there was some factor also incorporated that had a direct relationship to the product.

The author excepts certain operations on which he says that they do not use Standard Time; for instance, in placing. The reasons given for not applying Standard Time to those operations apply to practically every operation in our own plant, with the possible exception of the bisque-ware packing department, or the like, where the work is not particularly skilled.

The two operations that the white-ware manufacturers are interested in are the making and the glazing, and those are two important places for wage-incentive schemes. How should we get a relationship between this wage-incentive system and the quality of product?

In our works we used a scheme, although we are not satisfied with it, based on the amount of ware out of the glost kiln for the month, not counting the small pieces which are not important; that is, counting the tanks, but not the lids and light escutcheons, and disregarding these because the percentage of bad ones is negligible. We count the large pieces from a half washdown up, and then add all bisque broken pieces to that. We consider that summation, arbitrarily, as the number of pieces processed. That is practically what it is, although there are some endless turns on the flow sheet, but they are relatively small. The number of "A" pieces over the number processed gives a factor that we call plant efficiency. We set a bogey of 85 per cent. That may sound low, but it is not so bad in the ceramic industry. When we exceed that figure in performance—suppose we get 90 per cent, exceeding the bogey by 5 per cent—we tell the men that we will split fifty-fifty, we will give them two and one-half per cent on their wages. That works very much the same as this by-product bonus spoken of. We have in the sanitary plant men for wheeling clay. The two and one-half per cent is very small in money, and they have little to do with performance. The dipper, who is perhaps the highest-paid man, also gets the two and one-half per cent, but it is a much larger bonus, and his workmanship is vital to performance. We pay in proportion to the skill. The scheme has worked out very nicely. We keep a daily accumulative percentage and post it on the bulletin board, and no man will pass the bulletin board without stopping to see what the curve is for that day. It creates a spirit of rivalry, even when the bonus is very small. It is as much a matter of pride as the actual money they get.

Another bonus was simply given for quantity. We had a curious experience in starting up a plant in a coal-mining district, employing mostly former miners. The hardest thing that we had to overcome was the miners' habit of not working a full week. They would work three or four days and get $6 or $7 a day and then they had enough to spend for that week and we would see nothing more of them until the next Monday morning.

Of course, in running a tunnel-kiln they cannot do this, and although every one was on piecework, and paid in proportion to the work accomplished, we could not get them to work the full week until we offered a bonus for a full two weeks' work. In other words, if the man's quota was ten a day, as it is on washdowns, and fifteen days to a pay period, if he delivered 150 past the inspector in that pay period, he got a bonus. It was not two months before every one was making the bonus. On straight piecework they would not get the ware out, but yet just the offer of this small bonus of $5 a month, or something of the kind, where their monthly earnings were $200, helped put the thing across. In about two months the casting shop had doubled its production.

In the Bausch & Lomb Company in Rochester quality is pretty much of an item. They emphasize the quality factor as well as the speed factor. In other words, the bonus is based on the savings effected rather than on the speed alone.

The trouble with this group is we are too much in agreement. I think most of us are using the piecework system and agree that it is wrong. A suggestion has been made that applied to the sanitary casting shop—that we take a piece, for instance, that pays 70 cents, and if the man makes 10 pieces he will receive a $7 wage. Suppose we cut that rate down to 60 cents a piece, and then it is quite easy from our statistics to tell how many pieces that man gets out, each piece having his number on it and the date it was made. Now suppose we paid him 15 cents for every piece that came out A grade. Then he would receive 75 cents a piece for all the ones he had made that came out A grade. Suppose it came out B. You would give him, say, 7 cents for each B that came out, and he would get 67 cents or about a 3-cent penalty on his former rate. He would not be paid anything if the piece were broken but the 60 cents that he was paid originally for the piece. Of course it raises immediately a large question when it comes out B or broken as to whether it was the fault of the man

[6] Vice-President and Gen. Manager, Universal Sanitary Mfg. Co., New Castle, Pa. Mem. A.S.M.E.

or whether the slip was bad that day, or some other condition beyond his control was at fault.

S. H. Stevenson.[7] Our company's practice has been haphazard, and it has been based, like most other dry-press porcelain plants, upon the factor of speed alone. That is we try to get as much as possible from each employee and the factor of quality has not entered in to the extent that it should. We have about come to the conclusion that in the dry-pressing of electrical porcelain, on special shapes particularly, the law of diminishing returns operates. A man can work only so fast, and when he goes beyond that limit, quality suffers. There are certain definite limits in so far as speed is concerned. As for saying that the wage system used in our plant is the right one, we do not know.

Three things enter into the setting of rates and wages at our factory; first, our labor costs must be in line with our competitors'; second, we must compete with the other industries in our locality (which in our case is the rubber industry), in order to secure the most desirable men; third, we would prefer to pay the men wages that will make them contented, and not keep them until they find some other work. In our particular plant the policy is not to employ the cheapest labor, but rather to employ the best at prices which will keep it contented and still allow us to compete. Our wage scheme is certainly far from perfect and we are groping around for a better one.

The whole object seems to be that we are all selling the public on quality; that "We are making the best there is." I have often wondered if any intelligent effort has been made to sell the workmen in the plant on quality. Are the workmen who are producing the goods consistently sold upon quality? Is an effort made to have the workmen instilled with the idea of quality? Sell quality in the plant rather than in advertising to the public. I have often wondered if other plants have tried this and what effect it has on quality.

Joseph F. Barnes.[8] Has the author ever seen a group incentive plan where a bonus was paid for quality used in the ceramic industry? I have seen that work in the by-product division of the steel mills.

As you know we all like to pick flaws in this incentive wage plan. The worst fault of the ordinary piecework system seems to be that there are two kinds of jobs, good-paying and poor-paying piece rates. Apparently this will always be true because of constantly changing manufacturing conditions. Some foremen have to be regular diplomats to keep their men satisfied. In the sanitary potteries there are many times when a workman will have some pieces to make which pay him well for his time and others which pay him but poorly. Usually the good pieces are non-competitive items on which there is a fair margin of money.

It is true in almost any industry, that is, on piecework that there are "good jobs" and "poor jobs." Even in the Standard-Time system with bonus for production there are "good jobs" and "poor jobs." That system of payment has been worked in some of the shipyards where steel erection was analyzed and a standard time and a standard price were made on an erection job. Some jobs would be good jobs, and the crew could get done by twelve o'clock and then go home at the earliest quitting time allowed, say two or three o'clock, and make a bonus too. Other jobs would be "poor jobs" and the men would work hard all day and never make a bonus. The foreman, to even things up and be fair, had to sort these various jobs and give out a good job with a poor one and the men had to take them together.

Of course much of the weakness of standard time in the ceramic industry has been due to the efforts to adapt a system developed in a background of machine operations. In many of these operations the overhead-time cost of the machine used was far in excess of the operator's earnings. There the idea of Standard Time is to put a bonus on speeding that machine up. We will say that the man gets 60 cents for a given operation and the machine-time rate—the overhead on a milling machine or something of that kind—will be worth four or five times the man's rate. To get that operator to utilize the high cost of his machine-time overhead a premium must be put on piece production. That is what is common in the automobile and other industries of this kind. Say the Standard Time is worked out so that a man gets out an average of 100 pieces and makes $6 a day. If he makes 150, not only does he get paid on the basis of 150 pieces but the rate per piece is also increased by a small bonus.

Now, obviously, in the ceramic industry that will not work, because as has been said in previous discussion, the law of diminishing returns in quality hits hard. In the sanitary pottery with a fluid-cast process the ordinary workman will make 10 or 12 washdown water closets per day. If this workman studied the elemental motions of his work and tried to make 20 washdowns a day, he might succeed, but as a large part of the work is hand finishing the quality of this handwork might suffer a lot. I believe it has been done in exceptional cases but on the average it will not. Unfortunately defects often will not appear until the piece has been dried and fired and by then the piece will have passed through five or six men's hands. It then becomes difficult to hold a particular man or department definitely responsible for the defect in question.

In a system that the writer observed in the by-product works, every one in that plant got a bonus when efficiency went above the standard value. In terms of the sanitary pottery, say that we are ordinarily producing 92 per cent A grade, if we produce 95 per cent A grade that small difference often means the difference between loss and profit. In this by-product coke works when they got a certain percentage under distillation every man got a little bonus. We will say that the fireman's bonus on maximum efficiency was about 6 cents a day while the chief chemist received around 30 cents a day. Now you will say that the chief chemist could affect the efficiency ten times as much as the fireman. However, the fireman could let the steam go down. He could affect efficiency in turn just as well as the chief chemist. This bonus was worked out on a sort of hit-or-miss value, but the fact was that the incentive was there, and the strange thing is that it worked.

I understand that the bonus system mentioned was originally adopted as part of an effort to cut labor costs. Previously this had been attempted by arbitrarily cutting a man off the payroll here and there with the result that the plant was finally actually trying to operate without enough men to do the job properly under ordinary human efficiency. The superintendent could not hire any more men, and he had to get better work, so he put a premium on efficiency, and in this case he succeeded where the attempt merely to cut down on the labor and on the overhead had resulted in trouble here and trouble there. You know what it means when you do not have enough men to do a job. You go down to the ball mills, and they are not finished. They cannot get the slip out, it will not be finished by quitting time and that means four hours' overtime—so it goes.

The writer has never seen such a group bonus plan applied to the ceramic industry.

Louis E. Smith.[9] I am familiar with several contract or incentive schemes where we take certain kinds of wages in one plant and compare them to wages on similar work in another plant. I

[7] Secy-Treas., Akron Porcelain Co., Akron, Ohio.

[8] Eljer Company, Ford City, Pa.

[9] Jones & Laughlin Steel Corp., Aliquippa, Pa.

am also accustomed to comparison of two different piecework schemes to similar work in a third plant which does not have piecework. Each of these three divisions thinks its system is best and is always anxious for cost comparisons with the others.

Any plant without a wage incentive can make a good showing against a plant using piecework by picking good foremen, paying them well, and letting them run the job, but the same plant would do even better if a wage incentive were used.

I thought we would hear a lot of argument here today; I expected some one would say that all picework is wrong when quality is considered. We have not heard any expression on that side of the subject. All these systems apply more or less. I am not speaking for myself, but I see three or four angles and wanted and expected to get them all straightened out here, and I don't believe this has been accomplished.

## Author's Closure

Inasmuch as the installation of this system was a gradual one from which each piece was studied and put under the new system individually, there was not very much trouble encountered in doing so. The system itself appeared to be more fair than the piecework plan inasmuch as the men were guaranteed a definite day rate. This is particularly valuable in cases where the man falls down due to emergencies such as power's going off.

There was little or no suspicion aroused in the installation of this system due to the fact that it is simple and the men are able to figure their wage easily. It was our aim to give the men approximately the same wage under this system as they were able to make by a fair day under the piecework system.

There were no notable changes in quality of ware after putting this system into use. If there were a change it was probably for a better quality. With this system, there was less hounding of the men to obtain the quality which we ordinarily required. It appeared that the men were more willing to take time to bring up this quality.

There is no doubt that Standard Time will not work in many cases. We have operations such as the casting of large pieces in which one man is casting perhaps one hundred different shapes each day. Some of this work will run beyond the man's work-day period and in this time perhaps two or three men will attend to the filling of the molds, emptying, etc. This means that it would be difficult to determine the time which each man gives to a certain mold.

Another department in which it is difficult to institute an incentive system is the clay preparation department for dry pressing. In this department the men need only to prepare sufficient clay for the dry pressers. They are consequently limited by the amount of pressing which is done or the number of pressers at work. Obviously this overhead for the preparation of a uniform quality of material will vary considerably. At the present time we are preparing this clay by day work. In one dry-press department of my acquaintance, the men were paid in proportion to the aggregate wages of the pressers. This worked fairly well but was not simple in that the men in the clay-preparation department were able to calculate what their wage would be.

It is difficult to put the preparation of clay for saggers on an incentive system unless the whole department is operated as a gang. In a sagger department of my acquaintance the gang was paid a definite amount per hundred saggers delivered in first-class shape to the kiln placers. By so doing, the responsibility for drying as well as the pressing and preparation of the clay was placed in the hands of the gang.

There are certain operations whose times are predetermined, such as ball-milling. The time required for ball-milling a body in porcelain manufacture has been determined by the laboratory, and this of course is beyond any workman's control. Any speeding up of the process must be on operations not so limited. For this reason, as well as the fact that the preparation of the body is really so critical, only day work is used in this department.

The quality of the product is easily determined. The percentage of defective pieces is determined, of course, by the inspection department, which makes a visual inspection as well as electrical tests. The inspection department's tests also include the penetration of organic dye under 50,000 lb. per sq. in. hydraulic pressure. The electrical test, of course, is final and very definitely determines the quality of the ware. It is of course necessary to have competent foremen to maintain eternal vigilence in tracing causes of any defects which might occur. This is obviously necessary in the case of any incentive system which might be used.

As has been stated, it is necessary to have standardized methods of manufacture and standardized methods of determining quality of materials in order that there may be no interruptions or irregularity in the manufacturing process. Under our conditions there is little possibility for the men to complain of slip consistency due to the fact that this is standardized by the control laboratory. A large amount of our work is done by machinery and we do not therefore experience a large amount of trouble by intermittent losses such as are encountered where the production is more largely a matter of craftmanship.

Our inspection department is somewhat independent from our factory, and it therefore feels free to use its own judgment regarding the standards established. Inasmuch as it is independent of the porcelain factory management, the attitude is generally an independent one and consequently establishes a high standard.

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# The Control of Quality in a Manufactured Product

By JAMES H. MARKS,[1] DETROIT, MICH.

THE control of quality in a manufactured product can only be accomplished by coordination of design, provision of adequate and proper equipment and tools, establishment of proper controls to keep elements of the product within the limits of the standards set, and—by far the most important—the education of a controlling personnel.

The making of a fine product is the result of carrying out a vision. In order to manufacture an article of high quality by modern industrial methods, it is necessary for this vision to exist in the minds of the management the same as it is necessary for the image of a beautiful picture to be in the mind of the artist. In practice in industry this vision is called the design, so the first requisite is the preparation and development of a design in which the desired quality product is fully detailed and explained. The designer must put the requirements into the design that will bring out a well-balanced, completed product incorporating the high standards which are in his mind.

This interpretation of his wishes must be necessarily done by mechanical means. He must use drawings and specifications to outline what is to be made. The drawings show the outline of each part, what it is to be made of, the accuracy with which it is to be made, and the finish that is to be put upon it. These drawings are further amplified with elaborate and exhaustive specifications describing with utmost detail the quality of materials, and the method and kind of workmanship to be used in accomplishing the degree of finish desired. It is impossible to produce a quality article by modern manufacturing methods without such mechanical methods of interpretation. The designer must not only be capable of creating a fine product in his mind, but he must be capable of interpreting what the product is to be made from and how it is to be made and finished if the desired result is to be obtained.

When the design has been completed it must passed be into the hands of master craftsmen who know how to interpret the work of the designer and how to produce it. The mechanical organization which is to outline the means and methods for accomplishing the vision of the designer must know the machines, tools, and methods necessary and adaptable to accomplish the desired end. Where the workers are skilled only on one machine or even one operation on one machine, it is necessary to have machinery and equipment which is automatically capable of producing work of the desired accuracy without relation to the skill of the workmen. The mechanical organization which prescribes the machinery, tools, and methods to be used in accomplishing the desired result must be fully conversant with all that is available for economically doing work of the desired quality.

The next element in control is a combination of human skill and mechanical equipment. Gages are made to make certain that the work produced falls within the limits prescribed by the designer, and that the machines and tools have done their part in carrying out the plans of the master craftsmen. Any one who has had experience in manufacturing knows how difficult it is to set an absolute standard and work to it. There is no such thing as absolute uniformity. It is therefore necessary to not only have tolerance in limits, but human judgment as well to obtain the desired result. In order, then, to have proper control of quality, an organization must be developed to exercise this judgment and decide not only whether the parts made to enter into the completed product fall within the limits prescribed, but also whether these under certain circumstances are usable in combination with each other. This organization must be composed of experienced, thoroughly competent mechanics.

The sciences of physics and chemistry have amplified the ability of engineers to control the quality of materials. This application of science is usually represented in the modern manufacturing institutions by the mechanical, physical, and chemical laboratory. The functions of this organization and place are to interpret the designer's idea relative to the quality of materials in terms of written specifications; to test out the operation and features of the design, in order to advise the designer as to what he can accomplish; to prescribe methods of operation such as the heat treatment of materials, application of plating, process of painting, and similar others; and to be the check to determine that the quality of materials selected by the designer are used and that the specifications as to degree of finish are carried out. Measuring devices and gages are not enough to insure quality without the use of judgment and the knowledge of science as essential aids.

The most important thing necessary for accomplishment of a high standard of quality is the education of the entire manufacturing personnel to the standards desired, and this of all the things is the hardest to do. It is easy to obtain precision machines and tools and accurate gages, but it is very difficult to develop in the minds of a group of men one and the same thought relative to a standard of workmanship. A plant may have all of the machines and tools and precision instruments that are known today, but not have the ability to turn out a product of high quality. It is therefore necessary to have men of experience who are able to say, without perhaps being able to explain just why, either this thing will go or that thing will not go if the standard of product is to be maintained. This knowledge is a sort of a sense that is developed by years of contact between the master craftsmen and the designer.

The vigilance of this organization can never relax. We all know of cases in which some product has varied from one standard to another from time to time, at one time in its history having been recognized as the par excellence of quality and at some other time having passed to some mediocre place in comparison.

There can be no relation between quality control and production control except that production control, resulting in an uninterrupted flow of materials, makes quality control easier. If an organization sets out to maintain a certain standard of quality and obtain a certain amount of production constantly and at the same time, either one or the other must suffer. If a quality product is to be turned out, quality must come first and uniform rate of production must be secondary. To tolerate the use of improper material for the sake of uniformity of production is absolutely incompatible with quality manufacture. It has been proved again and again that the finest quality of work can be done in quantity production. The reason for this is that large quantities warrant large investments in machines

[1] Purchasing Manager, Packard Motor Car Co. Mem. A.S.M.E.
Presented at the National Meeting of the A.S.M.E. Management Division, Rochester, October 26 and 27, 1927. Slightly abridged.

and tools. The better the machines and tools, the finer the product. It does not necessarily follow that because things are manufactured inexpensively they are manufactured poorly.

The most important factors in accomplishing quality results are engineering as it carries out the design, and a trained personnel as it interprets the design in the finished product. The provision of adequate machines and tools is important but secondary. The ideal comes first, the organization, second, and the means to the end, last.

## Discussion

M. R. Edwards.[2] The smaller factory cannot hope to be able to draw up standard-parts lists, and procedures, and to index and cross-index standard designs for the convenience of the designers and draftsmen. In this respect it must more nearly conform to the older, more entirely human method whereby the designer followed out all the subsequent details of drawing, tracing, checking, etc. The modern trend is to specialize, with one expert to create, another to visualize, another to detail, and a last to fix standards and tolerances. Experience indicates that in the drawing office as in the factory, four experts can produce more than four times as much as one "all-around" man.

Decision whether or not to invest in tools is made in the large factory usually on the recommendation of the engineering force after exhaustive investigation of costs balanced against possible increased quality or production. The manager in the smaller factory, who must largely make his own investigation, must first study his product, bearing in mind that the operations which cost most usually offer the largest chance of savings. He must next thoroughly canvass the machine-tool field to find the best machine for his use. The writer at one time purchased a vertical miller to perform a certain operation and later learned that a new machine called a "nibbler" would have done as good work at one-fourth the investment cost. A complete, up-to-date file of machinery equipment should be at the hand of every such manager. While a manufacturing process is in the stage of transition to a better method (as all processes are doing), what may appear to be an improvement in quality or quantity may in reality be largely due to natural increasing skill on the part of the human element involved, and the new tools may be getting undeserved credit for the improvement.

No manager should economize on gaging and inspection in his drive to improve quality. His gages and precision tools are if anything more important than his manufacturing tools, in view of the modern trend toward the employment of less-skilled mechanics. A thorough, intelligently distributed line of gages will nearly pay for itself in savings of wages made by the possibilities of employing lower-grade inspectors. Experiences during the war bear out this point. The writer believes that in 99 cases out of 100, management is responsible for a poorly executed mechanical product. Every workman, no matter how low in intelligence, possesses some pride in his handiwork. Provide him with proper means and it will show up in the finished product.

Wm. E. Wheaton.[3] The author considers an ideal plant, but the greater number of our plants are not ideal. The management has to visualize the finished product, and not only has to consider the ideal of quality but in addition must consider very carefully the all-important item, cost. This necessarily causes some sacrifice of quality so as to meet competition. Due to our present competition it is necessary to first design an article that will fill the necessary requirements, consistent with the desired quality, in the cheapest way. After arriving at a decision as to the quality of the article to be produced, the writer then agrees with the author when he says that "first of all comes the educating of the controlling personnel." Coordination between the management and engineering department on the one hand, and the operating or producing on the other, is vitally essential. Those responsible for production are the most familiar with the ways and means they have at their command of producing the desired quality.

Our present method of conveying the information as to what is to be produced is by means of drawings and specifications. Let us only consider two schemes, one the drawings and specifications as required in a plant, such as an automobile factory, where they have continuous production, and the other a plant in which heavy machinery is produced which has a variety of sizes but a general standard design. To call for the same limits and specifications on the drawings used in the first shop for the second shop would not be practical nor would it allow of production at a cost that would meet competition. The same would hold good of the drawings used in the second shop, if one were to attempt to use them in the first. In the plant first described there would be frequent inspection, sometimes between each two operations and often during an operation. Gages, jigs, and fixtures would be used, and all modern equipment to produce the quality desired in the least time. While the second plant might have no inspection at all and yet produce an interchangeable product. The writer knows of one plant in which each workman inspects the work done on the operation just previous. All jigging is so arranged that the fit of the jig tool, or fixture depends on the correctness of the previous operation. As to the final operation, this is inspected by the assembly men.

Let us again consider the two plants from the standpoint of their mechanical equipment. Assuming their machine equipment being equal, let us consider their jigs, tools, fixtures, etc. The jigs or tools necessary to manufacture with are those such as drill jigs which produce parts to be fastened together and must be the same. Those used to increase production are such as holding fixtures for milling planing, turning, boring, and shaping, also tooling for automatic and semi- and multi-automatic machines. To secure quality control alone it is not necessary to have both types of tools, but only those necessary to produce. But to secure quality and quantity it is necessary to have both. It may be possible to produce an interchangeable product without either of these classes of jigs or tools, but the cost would be prohibitive.

Plants that do not have laboratories can get along very well as there are laboratories specializing in this work in most manufacturing centers, at which tests can be made or analyses had; and the mills and dealers today invariably supply material as ordered.

It may be true that quality and quantity are not directly related, but they are very closely related indirectly. Quality control can be more easily maintained when there is quantity production, but this does not mean that quality cannot be had apart from quantity production. Quantity can be had with or without quality control, but it seems that in most cases some quality is specified.

What has been said has been with a view of describing the way quality is maintained in a practical way, cost and quantity taken into consideration. The writer also believes that cost is as much a factor in the design or visualization of an article as the ideal.

[2] Mechanical Engineer, Bemis Bros. Bag Co., St. Louis, Mo. Mem. A.S.M.E.

[3] Works Manager, Walter Scott & Co., Plainfield, N. J. Assoc-Mem. A.S.M.E.

A. G. Peter.[4] The determination of tolerances is perhaps one of the most important factors for the control of quality, from the standpoint of the shop man. While it may be possible to fix limits of accuracy in the engineering department when the details of a design are worked out, still the writer believes that in the majority of cases these are the result of actual tryout in the shop during the early stages of production.

In the average plant, tentative tolerances are determined by the designer or the shop foreman, based on experience; and as tools and jigs are completed they are tried out on small lots, working to these limits. Eventually all of the parts are on hand and assembly begins. Then as difficulties arise, either in fitting the pieces together or in their subsequent operation on the test floor, these are noted and dimensions are adjusted accordingly. Through the early stages of production a constant changing of sizes goes on, until finally a point is reached where every part seems to be just right, which then becomes the standard of manufacture. These changes are all infinitesimal, often involving amounts measurable only with the finest of precision instruments, and in no wise involve the design. Nevertheless they have a tremendous effect in transforming the vision of the designer into a practical reality.

Manufacturing costs as well as the perfection of the finished article depend largely on the degree of precision required in making the component parts. Unnecessarily stringent demands of accuracy or finish add very little to the mechanical value of a product, and they may raise the cost beyond the point where it is salable. This must always be borne in mind: Quality should be maintained up to the point where it is consistent with the demands of the product as a practical and salable mechanism. Anything beyond this means money wasted in increased costs. Of course the determination of what is practical depends entirely on the function of the product, and on the market for which it is intended.

[4] Sale Engineer, Ferd. Pietsch Iron Works, Milwaukee, Wis. Assoc-Mem. A.S.M.E.

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# The Apprenticeship-Training Program of the Tri-City Manufacturers

By S. M. BRAH,[1] MOLINE, ILL.

THIS paper will treat the subject in three principal sections: first, a description of the community problem; secondly, an explanation of the system of apprenticeship training; thirdly, the results of the training under this system.

A community training program is of itself a complex problem. Whether the community be of large or small size matters little, for there are many minds that must agree on the basic principles of the training program as to policies of work schedules, rates of pay, and school or classroom work, or material to be used. After this particular community is outlined, a better idea will be gained of the need for unity in thought and action to make such a program a success.

The community under discussion is commonly known in the industrial world as the Tri-Cities, and includes the cities of Moline, East Moline, and Rock Island in the State of Illinois, and Davenport and Bettendorf in Iowa. These five cities located in two states have a total of forty-one companies, varying in size from 30 employees, in the smallest, to 1200 in the largest plant. Seven trades are included in varied types of shops and, almost without exception, a different degree of skill is required by each concern. Farm implements and accessories predominate in the list of articles manufactured, which includes laundry equipment, gas engines, electrical household appliances, harness, hardware, automobiles, railroad cars, scientific apparatus, elevators, jobbing castings, industrial locomotives, and pumps. Thus it can be seen that a variety of establishments participate in this program. The communities have much in common in every way, except politically. Residents in one city may work in another, shop in a third, and go to the fourth for their recreation. Each city has its own school system. The interests of all the industries are centered in one organization known as the Tri-City Manufacturers' Association, and it was under its sponsorship that the system of apprenticeship training herein described was inaugurated.

An expert staff was called upon to install a working program in the Tri-Cities. A personnel entered the field and made a survey as to the type of apprentices needed in the community and the number required for all purposes. This entailed a survey of 41 plants where metal-working operations were carried on. The number of employees was tabulated, various operations noted, statistics of turnover studied, and a report issued for each individual plant. The sum total of these surveys was analyzed and summarized and a brief was submitted to the Board of the Manufacturers' Association. The brief included the number of apprentices required in each trade and in each shop. The courses of instruction, rates of pay, schedules of work, and indenture forms were submitted to the Board and were accepted. It was then suggested by the personnel that a committee be formed and charged with the duty of carrying on the necessary administrative work. The manufacturers of each community were appointed as a body to present the problem to the schools for assistance in the way of classrooms and teachers. The response came whole-heartedly. For the first year or two it was decided that the schools in Illinois would be grouped under one teacher who would conduct the classes in each community as needed. The same idea was carried out in Iowa. After the plan was agreed upon by all school districts involved, the project was brought to the attention of the State Vocational Departments for aid from the Smith-Hughes fund. Their assurance of aid added zest to the work in hand and the problem of getting the apprentices was attacked.

A publicity program was planned to include talks to the graduating classes of all the schools, to parent-teachers associations, to clubs, and to civic organizations. An appeal was made to parents through the newspapers, showing the opportunities to be had in the trades in their own community. The initial response was not gratifying. However, the pessimism of many could be overcome by showing them as an example an apprenticeship program that had been going on for years right in the community; namely, that carried on at the Rock Island Railroad Shops at Silvis, Ill., which had been successfully training apprentices for the past 13 years.

Arrangements were made to interview the prospects with their parents or guardians and the plan was explained to them in full. A sufficient number were interested to make it possible to start and the first apprentice under this plan entered the employ of a foundry in Moline, April 28, 1926.

### System of Training

The so-called "system of training" so often spoken of is nothing other than work for the apprentice; the big factor being that he is actually given the work and not just promised it. It is the duty of the district supervisor to see that each apprentice is given the training called for on his indenture. It is also his duty to see that each apprentice attends school regularly and receives an increase in pay at the proper time.

Each apprentice is given an indenture wherein the schedule of work is outlined. For the machine-shop apprentice, this consists of the following operations:

| Schedule of work | Hours |
|---|---|
| Tool crib | 250 |
| Drill press | 400 |
| Screw machine | 400 |
| Shaper | 450 |
| Planer | 450 |
| Milling machine | 450 |
| Small tools | 150 |
| Engine lathes | 1800 |
| Turret lathes | 1200 |
| Boring mill and bar | 1200 |
| Grinders | 700 |
| Erecting and assembly | 950 |
| Special work (experimental room, drafting, etc.) | 1360 |
| Total | 9760 |

The total is based on 208 weeks of 47 hours each, or a period of four years.

The time distribution of the work schedule is varied to meet the needs of the shop and its equipment. The schedule serves as a guide for the shop supervisor or foreman in making out the indenture for his apprentice. A schedule of the rates of pay is included. The starting rate is twenty cents with a three-cent increase every six months.

The policy of having supervisors for each shop (that is, someone whose sole duty it is to instruct the apprentice) has not been

[1] Apprentice Supervisor, Tri-City Manufacturers' Association, Moline, Ill.

Contributed by the Committee on Education and Training for the Industries and presented at the Summer Meeting, St. Paul-Minneapolis, Minn., August 27 to 30, 1928, of The American Society of Mechanical Engineers.

carried out except in a few cases. The experience is that it will pay to do this but there has been a tendency on the part of the plants to do without the services of this man. In most cases, the foremen have taken the apprentices under their immediate care and have seen to their shop instruction. While this practice has been criticized by many, it is felt that since the training of apprentices is the object, the best training available is desirable as well as creditable. Whether or not the foreman is a capable instructor for apprentices is debatable, but the writer feels that if he is capable of training all others in his department, he certainly can train the apprentices. Usually, the criticism comes from those who are *not* training apprentices, and the writer wonders who is the greater sinner. One thing is certain: where an apprentice supervisor is maintained by the plant, a spirit of apprenticeship is built up in the minds of the foremen and the apprentices themselves sooner than when one is not employed. Upon this the success of a program depends.

A record of the apprentice's time and the work he has done is kept by the time-keeping department which turns in a monthly report to the district supervisor, so that he may enter this information on a control chart. A section of the control chart is shown in Fig. 1.

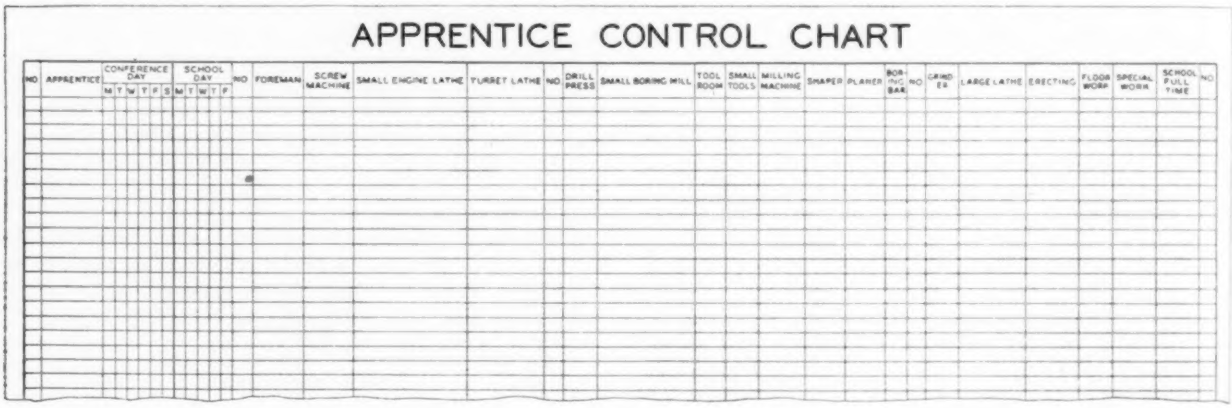


Fig. 1

(Small divisions under job headings indicate a definite number of hours. In the original, 200 hours are represented by each quarter-inch division.)

The information it contains is summarized as follows: The operations the apprentice has served on, the length of time spent on each, and the one engaged on at the moment (this latter by the use of a map tack). The shop has no other records to keep. It was felt that if the records were minimized, the foremen would take more interest in the program as a whole, for in many cases, worthy causes have died by the wayside because of their burden of records.

### Duties of the District Supervisor

The district supervisor's duties may be summed up as follows:

1 Plant surveys
2 Sell the management and personnel on apprenticeship
3 Interview and classify applicants
4 Act as mediator between apprentice, parents, and the shop
5 Maintain records as to changes of rate or work
6 Promote interest in the community by talks and written articles
7 Plan outside activities for the apprentices
8 Be ready to assist the plants, committees, school instructors, or apprentices on any matter on which he or they desire counsel.

### School Work

Correspondence courses have been provided as classroom-instruction material. A carefully selected list of subjects is chosen from the engineering and business courses. The courses contain mathematics, science, drawing, and related work (that is, texts on information relative to the machines and the processes involved in that particular trade). An outline of the text material in the machinist course is as follows:

*Mathematics.* Elements of arithmetic, fractions, decimals, ratio and proportion, weights and measure, powers and roots, mensuration, use of trigonometric tables (the high-school graduate is not required to take this work if he can pass a satisfactory examination), algebra, logarithms, slide rule, and geometry.

*Science.* Shop economics, measuring instruments, precision measuring instruments, mechanical principles, hardening and tempering, and heat treatments of low-carbon steel.

*Drawing.* Geometric and mechanical drawing (nine plates of the familiar geometric figures and their projections, and eight plates of various machine elements) and sketching in perspective and planes.

*Related Work.* Lathe work, drilling, milling machines, shaper and slotter, planer work, boring mills, gear calculations, gear cutting, grinding, and bench vise and floor work.

*English.* Capitalization and punctuation, letter writing, and English composition.

Each apprentice is enrolled in a course upon completing his probationary period (three months).

The classes are held in the local public schools. A regular recitation room is used, fitted with blackboards and drawing tables. The school board of each community furnishes this as well as the instructor. In Iowa, the instructor is one of the manual-arts-department men who gives part of his time to this work. In Illinois, the three communities have engaged one man to act as instructor in all three cities and the expense is prorated. The communities are later reimbursed to the extent of 50 per cent by the State Department of Vocational Education through Smith-Hughes funds available for such purposes.

The student attends class four hours per week in one period. He is expected to spend an equal amount of time in home study. A minimum requirement is set up and all apprentices are expected to meet it. The apprentice's time in the class is divided between mathematics, drawing, and related work in such proportions that his interest will not lag. The instructor selects the text to be studied and assigns the amount that the apprentice must work upon for the next class period. The text selected usually corresponds with the operation on which he is working in the shop. When he has completed the material he changes to a text related to the process on which he will be placed next.

The reason for this type of instruction material and procedure is self-evident to any one who has tried to instruct apprentice classes. The advantages are pointed out in the following:

1 Elimination of the necessity to review texts and authors to obtain a proper and related course
2 Elimination of the detail work—correction of lessons and lesson preparing
3 Home-study courses such as these can readily be studied at home and require the minimum of help from the instructor in the class
4 Each student can proceed at his own rate according to his mental capacity
5 Each student proceeds along the line in which he is most interested, whether it be the machinist, electrical, or some other trade
6 Grade- and high-school students as well as newly indentured and advanced students can be accommodated in the same class, keeping the number of classes to a minimum.

The cost of the courses is $100, payable at the rate of two dollars per month. If the amount is paid in cash, the price is $75. In the Tri-Cities this cost is borne jointly by the apprentice and the employing company.

### Cost of Apprentice Training

Nothing definite can be given on the cost of training apprentices, as many items vary over a period of a year. However, the following will show the cost for one year in the Tri-Cities:

| Item | Plant | Apprentice | School and Assoc. |
|---|---|---|---|
| Wages per year, average | $750.00 | | |
| Course | 12.50 | 12.50 | |
| Instruction and supervision | | | 40.00 |
| Miscellaneous (banquets, contests, activities, etc.) | | | 3.00 |
| Total cost per year for each party concerned | $762.50 | 12.50 | 43.00 |
| Grand total | | | $818.00 |
| Wages and expenses for each apprentice at school | | | $ 58.56 |
| All other expenses per apprentice | | | 68.00 |
| Non-productive expense | | | 126.56 |
| Productive labor expense | | | 691.44 |
| Total | | | $818.00 |

The above amounts are computed as follows:

The boy attends school four hours per week for 48 weeks per year—

$4 \times 48 = 192$ hours per year.

Minimum rates, 20 cents per hour; maximum rate, 41 cents—

$20 + 41 \div 2 = 0.305$ dollar.

| | |
|---|---|
| Amount paid boy by shop for time spent in school, $192 \times 0.305$ = | $58.56 |
| Cost of correspondence material, borne by boy | 12.50 |
| Cost of correspondence material, borne by shop | 12.50 |
| Salary of teachers, supervisor, funds for banquets, prizes for contests, etc. | 43.00 |
| Total overhead charges | $126.56 |

A total of $691.44 is paid for time spent in the shop.

### Results

The program herein described has been in operation less than three years and it is impossible to point to any number of apprentices that have finished their trade entirely under the program. However, it is felt that some measure of the success of the program may be gained from the following figures:

| Number of apprentices | End of first year | End of second year |
|---|---|---|
| At work in all shops | 84 | 125 |
| Attending classes | 60 | 119 |
| Number estimated in the survey | 125 | 250 |
| Maximum number called for in survey | | 425 |

| Applicants on file | End of first year | Second year | Apprentices at work second year |
|---|---|---|---|
| Machinist | 50 | 125 | 55 |
| Foundry | 48 | 60 | 28 |
| Pattern shop | 8 | 24 | 21 |
| Electrical | 5 | 30 | 3 |
| Plumbing and pipe fitting | 4 | 8 | 1 |
| Drafting | 8 | 23 | 0 |
| Sheet metal | 2 | 1 | 2 |
| Printing | 1 | 9 | 0 |
| Office | 2 | 6 | 4 |
| Manufacturing | 1 | 3 | 5 |
| Wood working | 2 | 20 | 0 |
| Unclassified | 14 | 11 | 6 |
| Total | 145 | 320 | 125 |

Examination shows that a large percentage of the applicants are not placed. This is due to no one particular cause. It has been deemed wise to go slowly and not overburden the shops with apprentices at the start. It must be remembered that the foremen are acting as supervisors of the apprentice as well as foremen in the department, and to burden them too heavily would be a mistake.

Applications on file, classified as to educational qualifications of the applicants, are as follows:

| | |
|---|---|
| Number completed grade school | 83 |
| Number completed first year high school | 80 |
| Number completed second year high school | 37 |
| Number completed third year high school | 13 |
| Number completed high school[2] | 107 |
| Total | 320 |

No applicants are accepted unless they have completed the eighth grade.

### Turnover

Tables of turnover showing the number lost in various trades during the first and second years, the trade in which the apprentice was indentured, and the reason for the turnover are tabulated as follows:

Turnover

| Cause | First Year Mach. shop | First Year Foundry | First Year Pattern shop | Second Year Mach. shop | Second Year Foundry | Second Year Pattern shop |
|---|---|---|---|---|---|---|
| Quit | 2 | 9 | | 1 | 7 | |
| Lack of interest | 5 | 1 | | 0 | 0 | |
| Lack of ability | 3 | 1 | 2 | | 1 | |
| Discipline | 3 | 1 | 1 | | | |
| Transfer | | | | | | 2 |

Total turnover, 37, or, based on percentage of total number apprentices at the time, 30 per cent.

Average monthly turnover for two years, 1.25 per cent.

Turnover School vs. Shop Fatality

| Cause | First Year Mach. shop | First Year Foundry | First Year Pattern shop | Second Year Mach. shop | Second Year Foundry | Second Year Pattern shop |
|---|---|---|---|---|---|---|
| Inability to master school work | 2 | 1 | 0 | 0 | 1 | 0 |
| Inability to master shop work | 6 | 2 | 0 | 0 | 0 | 0 |

General Summary

| Item | First year | Second year |
|---|---|---|
| Number of plants employing apprentices | 17 | 21 |
| Minimum number of apprentices in any plant | 1 | 1 |
| Maximum number of apprentices in any plant | 12 | 13 |
| Number of plants with one apprentice | 3 | 2 |
| Number of plants with two apprentices | 3 | 2 |
| Number of plants with three apprentices | 2 | 4 |
| Number of plants with four apprentices | 3 | 4 |
| Number of plants with five to nine apprentices | 3 | 5 |
| Number of plants with ten to thirteen apprentices | 3 | 4 |
| Total number apprentices at work | 84 | 125 |
| Plants dropping out | 0 | |

If these figures are a criterion of success, they are offered for their worth.

[2] Many applications have been filed, but applicants are not available as they have gone to college, or accepted some other position.

The success of this program is due in no small measure to the work of the executives that have served on the committee. Their duties have been many and complex. This committee is made up of five executives from each of the five cities involved, together with the secretary of the Association, and the apprentice supervisor. The committee passes on all matters of policy; acts as advisor to the supervisor; maintains contact with such outside agencies as the schools and state, conferring with them when necessary, acting for the manufacturers as a whole. They act as final agents in securing the cooperation of plants not yet participating in the program.

The committee is the keystone upon which the success of a community project depends, and in this case theirs is the glory of success.

## Discussion

Harold S. Falk.[2] The Tri-City manufacturers are to be highly commended for appreciating the importance of apprenticeship training and for the progress which they have made in the work. It is remarkable how few manufacturers are willing to undertake the training of apprentices although all of them realize that men are the most important element in industry. In spite of the attention which has been devoted to apprenticeship in recent years, the fact remains that, as a rule, only individual manufacturers have established apprenticeship.

But from the very nature of our American industrial organization, apprenticeship can hardly be expected to succeed in the individual plant and the Tri-City manufacturers are also to be commended for having made of their apprentice work a community enterprise and responsibility. Apprenticeship in the individual plant cannot be expected to succeed because the manufacturer who undertakes the training of apprentices without the cooperation of others will soon find that he is supplying mechanics for all the shops in the neighborhood and the burden is so unequal and so unfair that the training is very often soon abandoned. Apprentice training must be made a community responsibility, as we have often explained, with every plant in the district or neighborhood assuming its proper share of the burden of training the quota of mechanics for the district.

Manufacturers have associated themselves for research, for advertising, and for many other purposes. It is high time that they associate for the training of the men upon whom they must depend for the operation of their plants and their business. That such association is possible and profitable has been demonstrated by the manufacturers of the Tri-Cities.

In fact, it may be said that the association of manufacturers for the training of apprentices can be accomplished anywhere at all after the Tri-City Manufacturers have demonstrated its possibility in their case. I say this because it appears to me that the organization in the Tri-Cities has been brought about in the face of very unusual difficulties. A manufacturing community is usually confined to a single city in a single state and the establishment of apprenticeship involves arrangements with only one group of civic agencies, one school system, one city government, and one state apprentice law, if such has been enacted. The Tri-City industries are located in five different cities and these five cities are in two states, and if the organization of manufacturers for apprentice training is possible in such a confusion of municipal and state administrations, it ought to be possible under any circumstances whatever.

It is interesting to note that, in spite of their peculiar difficulties, the methods used by the Tri-City manufacturers have been little different from the methods used in other centers for the organization of apprentice training. These methods, with suitable adjustments for local conditions, should be successful everywhere. In the first place they have given their work publicity in the community as was explained. Experience has shown that apprenticeship cannot be made a success in the plant alone. The undertaking must have the cooperation of the people in the community, of the parents, teachers, and civic organizations. The people must believe in apprenticeship and must see in it an advantage for their sons.

Again, the Tri-City manufacturers found that a committee of executives for the direction of apprenticeship is essential for successful community apprenticeship. Unless such a committee exists, there will be discrepancies in training periods, contract arrangements, schedules of work and pay, and other important features of apprenticeship in the various plants, and serious differences of the kind will destroy the unity of the plan.

Arrangements with local school authorities for theoretical instruction of apprentices is indispensable in a community project for the reason that the small plant cannot afford to maintain a school of its own and the large plant will find it more profitable to utilize the public institutions than to maintain a teaching organization. The work of the Tri-City manufacturers in bringing about cooperation between themselves and five separate school systems in addition to the vocational education departments of two states appears to be quite remarkable and shows what may be done when enthusiasm and determination are applied.

The author makes the statement that apprentice supervisors are not employed in the individual shops and that in most cases foremen have assumed the care of the apprentices. He goes on to state, "Whether or not the foreman is a capable instructor for apprentices is debatable, but the writer feels that if he is capable of training all others in his department he certainly can train the apprentices." The instruction of apprentices does depend upon the foremen and, except for special shop instructors, no better teachers of practical work than the foremen can be found.

However, a distinction must be made between apprentice instruction and apprentice supervision, although the two functions may be combined in one person. Apprentice instruction means teaching the apprentice the various operations which are a part of the training course. Apprentice supervision involves the planning of courses, the maintenance of school and other outside contacts, the selection of boys for apprentice training, the transfer of apprentices from one department or operation to another, the solution of personal problems of the apprentices, and so forth. For this work the foreman is not qualified because he has neither the time nor the opportunity to do it, however well he may be able to instruct the apprentices. Therefore, apprentice supervision must be provided in addition to the instruction given by the foreman. Undoubtedly, this supervision is very well taken care of in the Tri-Cities by the district supervisor. Since there are 125 apprentices in the district according to the latest report, it is still possible for the district supervisor to maintain personal contact with all of them. However, experience indicates that this is about the limit for one man, and if additional apprentices are engaged in the district it will be necessary to put on an assistant supervisor for the district or an apprentice supervisor in one or the other of the larger manufacturing establishments. Apprentices need a person who devotes all his attention to their welfare and to whom they can bring their problems, just as a dean of men and of women and personal advisors are necessary in a university in addition to the professors and instructors.

Finally, it would be interesting to know the basis of the survey of the Tri-City district for the determination of the proper quota of apprentices. There is some disagreement as to the

[2] Vice-President, Falk Corporation, Milwaukee, Wis. Mem. A.S.M.E.

method of establishing the quota. To fix the number of apprentices arbitrarily as one-tenth of the total employment or one-fifth of the skilled mechanics is not satisfactory. Some authorities maintain that the number of apprentices should be determined by the requirement of the district from year to year. Others maintain that the facilities for training in the shops should determine the number. It would be interesting to know how the quota for the Tri-Cities was determined, although we all appreciate that it was impossible to include a full description of the method in a short paper already crowded with pertinent information.

Harold W. Fitch.[3] After reading the paper the writer wishes to express his appreciation of the excellent manner in which a complex problem has been handled. It is no easy task to organize and coordinate the efforts of a considerable number of conflicting interests and Mr. Brah and the board of the Tri-City Manufacturers Association are to be commended on their achievement.

While it is obvious that the program described was designed to meet a local condition, there are three points which are of primary importance as applicable to any system of apprentice training.

1 The author states, "The 'system of training' so often spoken of is nothing other than work for the apprentice—etc." Unfortunately, what is so often referred to as a "system of training" is nothing of the sort but, rather, a lack of system, the apprentice being turned over to a foreman who places the boy where he will least inconvenience him. By observation or the method of "trial and error" the boy may eventually attain some degree of proficiency. When the apprentice feels that he should be transferred to other work it may even be necessary for him to make such a nuisance of himself that the foreman is glad to be rid of him. This, obviously, is not a system of training but, rather, the results of the lack thereof.

Any "system of training" should provide a printed outline showing the time to be spent on each machine or operation as well as the logical sequence of items. It must also provide a means of keeping a record of the performance of each boy on the various operations. (This point was not touched upon in the paper, but it is assumed that provision has been made to keep such records.)

2 As a former foreman the writer wishes to take issue with the statement that the foreman should train the apprentices. The author states, "If the foreman is capable of training all others in his department, he certainly can train apprentices." The writer contends that, with an apprentice training system functioning properly, the foreman has little necessity for training the men who are graduates of such a system. They will have been trained as apprentices and therefore do not need a considerable amount of further training.

Because of the multiplicity of his other duties, and principally because of the fact that production is the primary object of his department, the foreman will all too often sacrifice training for production. We have tried to have foreman instruct apprentices, but the results have not been satisfactory.

3 Apprentice instructors, even though they may travel from shop to shop supervising and instructing the apprentices, have proved to be of great value on the New Haven. Owing to our having over 200 apprentices scattered among a dozen shops and engine-houses, it has been necessary to utilize traveling instructors while also relying, to a certain extent, on the foreman to carry on the training in the absence of the instructor. It is our observation that where instructors can devote their full time to one point the best results are obtained.

[3] Assistant Engineer, N.Y.N.H.&H.R.R., New Haven, Conn. Jun. A.S.M.E.

C. A. Prosser.[4] The writer has been watching the apprenticeship situation for some fifteen years. Dunwoody Institute is engaged in training apprentices for three railroad systems, and from this experience certain conclusions have been reached, right or wrong.

Apprenticeship of the old type is almost disappearing. The writer's experience leads him to believe that this is a day for practical experiments; we have too much talking and not enough action. Many schemes will have to be tried because there are many conditions to meet.

The Tri-City scheme is a real experiment and in many of its aspects it is wisely conceived. It must be watched to determine just exactly the conditions for which it is fitted, what are its weak points, what are the failures, and what are the points of success.

There are many organization features of the scheme that are admirable. The employers of these cities have pooled their activities and have assumed certain responsibility for the youth of the community. They have set up a scheme of cooperation with the public school system. They have attacked the exploitation of the apprentice on the job by setting down on paper the amount of experience he must acquire during his apprenticeship.

The scheme may be questioned on its instructional side. Because a man is a foreman he is not necessarily a good trainer of apprentices. Teaching is as much a trade as foremanship. Ten out of every eleven hours of an apprentice's time is spent in the shop, and the foreman either makes him, leaves him indifferent, or wrecks him. If ten hours of poor training is supplemented by one hour of good training, little good can be accomplished. In a check-up of foremen in the printing trades to learn the methods of breaking in green men, fifteen men replied and outlined eight different methods. They cannot all be right.

The writer does not agree with the plan of having a correspondence course of study taught by local schools, as it is taught in this scheme, nor does he believe that a manual-training instructor is qualified to teach such a course. He challenges the teachings of abstract mathematics to boys in training as apprentices to a trade. The habit of using mathematics involves two things, one, analysis of the situation, and the other, the application to that situation of a formula. In investigations of the use of higher algebra and abstract geometry by tradesmen, the writer has never seen a mechanic who could say what methods he used. It may be that there are engineers who bring to bear in their daily work a knowledge of basic algebra and geometry, but this is not true in the trades. A mechanic analyzes the problem he has to meet in the shop and decides which formula applies. He has to be a master of the use of that formula before he solves the problem. Too many times engineers assume that a knowledge of higher algebra and geometry is necessary for the solution of a job by a mechanic when this is absolutely not true.

The writer believes that it is a waste of time to teach abstract algebra and geometry to boys in high school. The writer also believes that the way to teach a boy to read blueprints is to teach him to read blueprints. Such a course as the one offered at the Tri-City school is an attempt to make draftsmen. If we are making mechanics we should teach them the trade in so far as it applies to the work a mechanic has to do. Let him take additional training later if he has an ambition to become a draftsman.

The author points out that a correspondence-school instruction course is used because it supplements the weaknesses in the teaching force. No correspondence-school course of instruction will ever take the place of the living teacher in the class. There are exceptional men of high ability and long experience who never do well in a class and who get a lot out of a home-study course. The correspondence school has a definite place in American life,

[4] Director, Dunwoody Institute, Minneapolis, Minn.

but in the opinion of the writer it has no place in teaching a trade to unskilled and inexperienced boys by absent treatment through a teacher unfamiliar with the trades taught.

In the end the employer pays the bill. With a cheap scheme he saves money at the spigot and wastes it at the bung. If the overhead is reduced, the employer pays for it in the poorly prepared apprentices. If he lets the community do it and pays the tax, he meets the burden. If he sets up a scheme that costs more money but is more efficient, he pays the cost but reaps the better results.

R. K. Erskine.[5] We are not so much concerned with highly skilled mechanics as we are with leaders of men, men able to cooperate with other men, and good instructors. What we demand in our business is highly skilled foremen, good instructors, and good set-up men. Two years ago we established a course and had one man from the Extension Division of the University over twice a week for evening sessions. Instead of getting new men and starting them in as apprentices, we selected a group of men from our own works-foremen, and prospective foremen—men who we thought would develop. These men were trained for the job for which they were best suited. If a man shows ability in cooperating with the other men, we may figure that he will make a good instructor, and that he is well fitted as a foreman.

What we demand of a foreman or instructor is leadership, ability to cooperate, as our work passes from department to department, the schedules depending on how foremen realize the problem. We demand good instructors. Our business is reasonable and we have to take on new men, train them, and probably lose most of them after a period of five or six months. Then we demand a good basic understanding of the trade. Some foremen have taken advantage of the trade schools in Minneapolis and it is interesting to hear a paper such as this because in our own case we are looking for just such things. We appreciate the work that is being done.

P. S. Van Wyck.[6] The writer stated that instead of teaching men as draftsmen, blueprint reading and shop sketching should be emphasized, the sketches to be suitable to work from in the shop. The writer questioned the use of obsolete correspondence-school tests, favoring up-to-date textbooks in preference, but agreed that newly revised correspondence-school texts would be equally acceptable. He preferred to use job sheets with the tests as references, for his own part.

Luther D. Burlingame.[7] The Brown & Sharpe Manufacturing Co. has had an apprenticeship system for sixty years which it is interesting to compare with one just started. The Brown & Sharpe apprenticeship system is sufficient unto itself because there are nearly two hundred apprentices in this one factory. In developing skilled workers we are also cooperating with other manufacturing plants in Providence and vicinity in carrying through a cooperative scheme which we believe can be adopted in any city.

It is interesting that a foreman very often does not want an apprentice, and that in the Tri-Cities this attitude has been changed so that foremen welcome apprentices. The grinding and gear-cutting departments of the Brown & Sharpe Co. were considered outside of the regular apprenticeship courses and apprentices did not go into them. When it was decided that apprentices should receive instruction in these departments, the foremen "threw up their hands" and said that they could not be bothered. However, they were persuaded to try the scheme, and one of the boys first selected to go into the gear department did so well that the foreman not only wanted him but asked to retain him for a longer period than had been planned as he had some important work he wanted him to do. Actual contact changed the feeling on the part of the foremen and they no longer objected to apprentices in such special departments. They had thought of the boys as just starting in, whereas they were two or three years along in the course when they came to these departments and had matured to a point where their training was worth while.

The thought has been expressed that the old apprenticeship system has passed away. Instead it has developed into the modern system which is far more efficient and gives much better training. In our training, certain boys show an aptitude and express a desire in the fourth year for foremanship and they are trained for and developed into foremen. Under the present system of apprenticeship the boy is getting a far better chance than the apprentice formerly did.

C. J. Freund.[8] In discussing foremen's qualifications for teaching apprentices, a distinction should be made between qualifications for teaching the practical side of apprenticeship—operation of machines, grinding of tools, etc.—in the shop and qualifications for teaching related trade subjects, mathematics, etc. Certainly, as has been pointed out, the foreman is seldom an ideal instructor; undoubtedly a professional teacher is much better. However, only the largest plants can afford full-time professional teachers in the shop.

Several years ago in Milwaukee, manufacturers built up a considerable fund to build a trade school which could accommodate about 400 boys at many different trades. The school has since failed as a private enterprise and has become a city trade high school. The reason for the failure was that it was soon discovered that although there was a great amount of special equipment, large building, etc., it was impossible to train the number of mechanics required in the district.

There are now in Milwaukee about 950 apprentices in the machinery-building trades. The investment in a trade school which would be required to teach 1000 boys in machinery building alone, not to mention leather working, food industries, etc., would be so large as to be impracticable. This forces the employer to utilize the foreman as an instructor of apprentices on the machinery in the shop, and this is a more feasible plan, regardless of the foreman's limitations than a limited amount of equipment and a limited number of boys in a trade school, in spite of the better trained and more efficient teachers. Of course, the plan does not prevent the apprentice from spending part time in a school with professional teachers who teach him related trade technique and as much actual machine operation as time will permit.

There is another thing which the apprentice gets from the foreman which he cannot get from anybody else, and that is a proper attitude toward production. In the case of an apprentice, training is the first consideration and production is secondary but the apprentice is apt to interpret this as meaning that training is everything and production is nothing.

He would willingly spend a day or a week on one small piece in a lathe if he were not working under a foreman, but the foreman is pressed by the management for production while he is training the boy, and therefore he will teach him better than any one else can how to get out his work, how to save time, how to be

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[6] Department Head, Machine Shop, Dunwoody Institute, Minneapolis, Minn. Assoc-Mem. A.S.M.E.

[7] Industrial Superintendent, Brown & Sharpe Mfg. Co., Providence, R. I. Mem. A.S.M.E.

[8] Apprentice Supervisor, Falk Corporation, Milwaukee, Wis.

efficient, so that when the boy finishes his apprenticeship he becomes a real factor in production.

A distinction must be made also between the instruction and supervision of apprentices. In the ordinary plant, foremen must be instructors of apprentices but they have not the time to be supervisors.

## Author's Closure

In reply to Harold S. Falk's discussion: an assistant district supervisor has not been added, but in place, whenever a shop has more than ten apprentices, some individual has been appointed acting supervisor for that plant.

In reply to Harold S. Fitch's discussion: confusion, no doubt, resulted from the paper in the statement that no system of training was used in the Tri-Cities and later the schedule of work was included. If a printed schedule of work may be considered system, there is one in use in the Tri-Cities. Mr. Fitch does not seem to understand that the foreman is the only one provided by the management to train the apprentice. A misunderstanding must have resulted as no apprentice instructors exist for shop work. They are concerned only with the class work which is carried on in the local schools.

In reply to Doctor Prosser's discussion, as to the desirability of foremen as instructors: the author merely states that foremen are capable to instruct and this method was resorted to inasmuch as teacher trainers were too expensive for companies having five or less apprentices. No two educators would agree on what mathematics is most desirable for vocational work, but all are willing to agree that the fundamentals must be firmly established before future work can be attempted. That is what has been done in the Tri-Cities. The vocational mathematics is included in the text of related work. No better material has been offered than correspondence-school text and all weaknesses are being overcome by classroom supervision.

The Doctor's contact with manual training teachers has surely taught him that there are men of *all* calibers in this field and we feel that ours is of the *higher* caliber, fitting him for the task at hand.

Replying to P. S. Van Wyck: inasmuch as sketches are seldom used in production shops, actual line drawing is taught to familiarize the apprentices with drawings so that they may read blueprints intelligently, accurately, as well as quickly.

The correspondence-school test material is revised regularly and in some instances, yearly, and is more recent than any other type of text material available.

The author is in perfect accord with what Mr. Burlingame had to say.

C. J. Freund has answered Doctor Prosser's argument on the foreman's qualifications as a teacher of apprentices. The author wishes to say that the foreman does not act as instructor in teaching classroom subjects. Nor does he act as supervisor. The classroom work is done in the public schools and the supervision is taken care of by a director indirectly employed by the cooperating company.

# An Industrial-Plant-Location Study

## Results of an Analysis Illustrating the Factors to Be Considered in Locating a Plant

By EMMETT B. CARTER,[1] NEW YORK, N. Y.

THE FACTORS to be considered in locating the plant which has been taken as an example in this study include:

1 Trade possibilities for expansion
2 Low distribution costs and speedy delivery
3 Cost and quality of raw material
4 The first cost of the plant and the resulting overhead costs
5 The cost and quality of labor.

### Trade Possibilities for Expansion

The owner of the plant had decided to build a plant to produce 100 tons per day. He had been influenced in this decision by his ability to sell that output and his ability to raise enough money to build such a plant, but for an engineering analysis of plant location more information was necessary. For example, the following questions come to mind:

1 How much land is required for future development? To answer this question a general survey of the trade is necessary.

2 Might this plant eventually be called upon to supply several times the capacity at present assumed? Government reports are of great value in determining the possible magnitude of the industry and its probable growth.

3 With a knowledge of the present distribution of the product the factor governing distribution must be decided upon. Is it population, per capita wealth, climate, or some other factor?

4 Is the geographic distribution likely to remain about as it is now? If not, what change is likely to occur?

### The Cost of Distribution

Having completed a study of the potential market, definite quantities were used for sales forecasts, and maps and charts were prepared to visualize the situation, especially the sales distribution by states, more clearly. This is followed by a complete tabulation of distribution points and probable shipments to these points.

From the maps of sales distribution and a knowledge of freight rates it was seen that a good distributing point lay somewhere in the state of Pennsylvania. However the industry which is considered in the present analysis receives the bulk of its raw material from Europe and full cargo steamers should be able to unload directly into the plant; and therefore with the state of Pennsylvania in mind as a good distribution point, New York, Philadelphia, and Baltimore appeared to be possible locations.

A further study of the raw material, however, disclosed the fact that one ingredient of which considerable tonnage is necessary should be purchased in New Hampshire; hence the New England ports had to be considered. This widened the possibilities so that the Atlantic Coast ports from Boston to Norfolk had to be considered.

### Freight Rates

A tabulation of comparative freight costs from the locations considered was then made as is indicated in Table 1, in which are included only enough destinations to illustrate the method used.

TABLE 1 COMPARATIVE COST OF FREIGHT ON FINISHED PRODUCT TO CONSUMER

| | | Freight costs in dollars when shipped from | | | | | |
|---|---|---|---|---|---|---|---|
| Destination | Tonnage | Boston | New London | New York | Wilmington | Baltimore | Norfolk |
| Ashtabula, O. | 5,800 | 51,968.00 | 51,968.00 | 49,358.00 | 46,632.00 | 45,675.00 | 44,834.00 |
| Buffalo, N. Y. | 1,670 | 12,909.10 | 12,909.10 | 11,973.90 | 11,973.00 | 11,973.90 | 13,660.60 |
| Cincinnati, O. | 113 | 1,241.84 | 1,241.84 | 1,241.84 | 1,190.94 | 1,164.93 | 557.58 |
| Grand Rapids, Mich. | 1,118 | 13,024.70 | 13,024.70 | 13,024.70 | 13,521.60 | 12,275.64 | 10,520.38 |
| [Other destinations and figures pertaining to them have been omitted.] | | | | | | | |
| Total costs | | 317,728 | 323,800 | 312,083 | 315,575 | 314,830 | 329,563 |

One may think that if it costs 30 cents to ship a commodity 100 miles it should cost something like $3 to ship it 1000 miles, but freight rates have been built up on a system of literally "charging what the traffic will bear." It has been to the interests of the railroads to help build up business for industries on their lines, and when one of these industries could show where they absolutely required a lower rate to develop new business or to invade a territory served by a competitor, the railroads have tried to help them. For example, industries located in New England on the New Haven Railroad have the same freight rates for points west of Harrisburg as those shipping from New York City.

Special import rates exist at a few ports and help to put these ports on a better basis in competition with other seaboard cities. For example, a domestic rate from Boston to Bloomsburg, Pa., is 34 cents, while the import rate is $25^1/_2$ cents.

### Commodity Rates

Special products have been favored with commodity rates from and to certain points where a special demand has existed. A manufacturer should always present his request for such a rate to his railroad if he can show that his competitor has a commodity rate and thus is securing an unfair advantage to reach a certain market. The possibility of securing additional commodity rates must always be considered in plant-location work.

### Cost of Importing Raw Material

In the case under consideration, the largest tonnage of raw material comes from Spain in full cargo steamers drawing 25 ft. of water. This required a study of Government maps of harbors. As the cost of unloading and shipping any distance by rail was very expensive, it indicated that the plant must be on deep water.

A review of port conditions for the principal ports was made and a sample of the study for Baltimore is included to indicate the points covered. Due to the distance which these steamers must travel, the question as to which one of the North Atlantic ports was selected for the plant appeared to make no difference in the cost of ocean freight.

It might be added that the question of anchoring ships and barging raw material to a plant having shallower water was considered, but the two spots under consideration, namely,

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Narragansett Bay and the Delaware Bay, were thought to be unsuitable for such operations due to high winds and ice conditions in winter months.

The raw material from New Hampshire amounted to 1220 tons per year, and the freight costs to different locations were about as follows:

| | | | |
|---|---|---|---|
| Boston | $5734 | Philadelphia | $8510 |
| Providence | 5841 | Wilmington | 8747 |
| New London | 6417 | Baltimore | 9979 |
| New York | 8064 | Norfolk | 11346 |

## Port Surveys

It was necessary to make a survey of expenses and working conditions at various ports, and that which was made for Baltimore is given here as an example. These expenses are summarized in Table 2.

TABLE 2 ACCOUNT OF EXPENSE OF A STEAMER DISCHARGING AT BALTIMORE

| | |
|---|---|
| Entrance at Custom House | $ 5.00 |
| Clearance at Custom House | 5.00 |
| Custom-House fees | 5.00 |
| Quarantine fee (health officer) | 10.00 |
| Running lines (in and out) | 5.00 |
| Fumigation (about) | 90.00 |
| Coopers, if required, $8 per day | |
| Tally clerks, if required (estimated) | 350.00 |
| Wharfage, no wharfage account, steamer at usual railroad berths, agency fee | 100.00 |
| Use of preliminary bond | 10.00 |
| Postage and miscellaneous | 10.00 |
| Telegrams, telephone, etc. (actual cost)(estimated) | 15.00 |
| Pilotage inward, say, 23 ft. at $5.50 | 126.50 |
| Pilotage outward, say 13 ft. at $5.50 | 71.50 |
| Tugs, docking, about | 75.00 |
| undocking, about | 75.00 |
| (No shifts figured.) | |
| Stevedoring, discharging 5000 tons at $1.50 per 2240 lb. | 7500.00 |
| Tonnage tax, 3800 net register tons | 228.00 |

Note: Average rate of discharge, 650 tons per weather working day of 8 hours.

each direct call, but the tax paid within any period of twelve months is not to exceed 10 cents per ton.

If vessels are plying between both 2-cent and 6-cent ports, the total tax paid within any period of twelve months is not to exceed 40 cents per ton.

Entrance and clearance charges made by Government authorities amount to $2.50 to $10 for entrance and $2.50 for clearance.

Brokerage fees are $5 for entrance and $5 for clearance.

Custom-house bond charge is $10.

*Dockage and Wharfage.* Vessels discharging or loading at piers owned by railroad companies do not pay any wharfage if any portion of the cargo moves over the railroad where vessel is berthed. On material moving over side or over the dock of a railroad other than the railroad owning the pier at which steamer is docked, there will be a top wharfage charge of 12 cents per 2000 lb. This also applies on freight delivered to lighters of railroads other than the railroad at whose dock the steamer is discharging.

*Towage.* Towboat companies have fixed tariffs. The average cost of a shift is $80 to $100. The average cost of docking and undocking is about $60 to $70 total per steamer.

*Boatmen.* Charges for running ship's lines are $3 for mooring and $2 for unmooring each shift.

*Watchmen.* The rate for watchmen is about $4.50 per day of 12 hours.

*Stevedoring.* Rates of stevedores depend upon the commodity to be handled.

*Tally Clerks.* Clerking is contracted for by the ton or by the day.

*Water.* Fresh water can usually be obtained at the railroad piers at a cost of $1 per 1000 gallons. Delivery by boat is 65 cents per ton.

*Surveyors.* For inward cargo, the hatch-survey charge is

TABLE 3 ESTIMATED COSTS OF PLANTS—AN APPROXIMATE COMPARISON

| | If built at | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Boston | Providence | New London | New York | Philadelphia | Wilmington | Baltimore | Norfolk |
| Buildings and equipment | $ 840,000 | $810,000 | $810,000 | $890,000 | $840,000 | $785,000 | $790,000 | $780,000 |
| Land | 100,000 | 80,000 | lease | 100,000 | 85,000 | 50,000 | 70,000 | 40,000 |
| Dock or bulkhead | 70,000 | existing | existing | 60,000 | 55,000 | 50,000 | 40,000 | 40,000 |
| Dredging | 25,000 | none | none | none | none | 25,000 | 30,000 | 35,000 |
| Grading | 20,000 | none | 5,000 | 15,000 | 10,000 | 25,000 | 15,000 | 20,000 |
| Piling for plant | 75,000 | 30,000 | 40,000 | 75,000 | 15,000 | 35,000 | 25,000 | 20,000 |
| Approach railroad | 20,000 | existing | existing | existing | 15,000 | 20,000 | 10,000 | 12,000 |
| Approach road | 8,000 | existing | existing | 15,000 | existing | 10,000 | existing | 5,000 |
| Water supply | 10,000 | existing | existing | 40,000 | 15,000 | 15,000 | 10,000 | 25,000 |
| Total cost of plant | 1,168,000 | 920,000 | 855,000 | 1,195,000 | 1,035,000 | 1,015,000 | 990,000 | 962,000 |

*Pilotage.* Rates for pilotage for Chesapeake Bay: Vessels drawing more than 13 ft., $5.50 per foot deepest draft.

*Quarantine.* Federal quarantine station is located about six miles below Baltimore. Each vessel is charged $10.

*Fumigation.* Fumigation is performed by the U. S. Public Health Service only.

*Custom House.* Vessels coming directly from foreign ports, except ports situated in countries enumerated below, must pay a tax to the Federal Government of 6 cents per ton net register for each entry, but the total tax paid within any period of twelve months is not to exceed 30 cents per ton.

Vessels plying between the United States and the following countries are subject to a tonnage tax of 2 cents per ton net register for each direct call, but the tax paid within any period of twelve months is not to exceed 10 cents per ton: Canada, Bermudas, Mexico, Bahama Islands, West Indies, Central America, and that portion of South America bordering on Caribbean Sea up to the Orinoco River.

American, Norwegian, and Swedish vessels plying between ports of Norway, Sweden, and the United States are required to pay a tonnage tax of 2 cents per ton net register for

$15. For outward cargo, the New York Board of Underwriters' survey charge is usually $15.

*Bunker Oil and Coal.* Bunker oil and coal can be secured at favorable rates and upon short notice.

## The Cost of the Plant

A considerable variation was found in the cost of buildings and equipment erected in the different localities. The labor-union regulations such as prevail around New York boost costs materially in such cities. This was especially true in concrete and pipe work.

In the study of the properties available, the existing buildings, roads, and water supply were of course taken into consideration as well as the amount of piling required for buildings and docks and especially the length of piling that would probably be required.

Taxes also were determined as they entered into the cost of plant overhead. Dredging became an item in plant overhead when docks would not have extended to government channels.

## Real-Estate Surveys

A personal inspection was required of properties available, and

TABLE 4 SURVEY OF PROPERTIES AVAILABLE AT BOSTON

| Description of Property | Approximate cost of land |
|---|---|
| No. 1. On Mystic River. Requires dock and piling for plant and some dredging | $200,000 |
| No. 2. On Commercial St., served by deep water on the Charles River. Dock required but no dredging | $400,000 |
| No. 3. On Chelsea Creek. 25 ft. of water at property. Dock required | $100,000 |
| No. 4. Medford on the Malden River. A barging proposition up the Malden. This is marsh land. Requires dock, piling for plant, no dredging | $40,000 |
| No. 5. East First Street, South Boston, near Army Base. Assumed value | $400,000 |
| No. 6. On Malden River, near U. S. Government property. It would be a barging proposition | $20,000 |
| No. 7. South Boston, on Boston Harbor, 1/4 miles from 35-ft. channel. A channel 50 ft. from property to main channel would cost $75,000. Has railroad siding | $175,000 |

in one investigation all properties along the Atlantic Coast having 25 ft. depth of water and large enough for the plant from Maine to Virginia were investigated. The results are given in Table 3.

TABLE 5 A COMPARISON OF THE PRINCIPAL VARIABLES IN OPERATING COSTS FOR DIFFERENT LOCATIONS

| | Boston | Providence | New London | New York | Philadelphia | Wilmington | Baltimore | Norfolk |
|---|---|---|---|---|---|---|---|---|
| Delivery expenses on raw material from abroad | $77,630 | $80,505 | $80,460 | $32,225 | $81,125 | $79,080 | $76,080 | $79,980 |
| Freight on domestic raw material | 5,734 | 5,841 | 6,417 | 8,064 | 8,510 | 8,747 | 9,779 | 11,346 |
| Overhead on plant | 93,440 | 73,600 | 68,400 | 95,600 | 82,800 | 81,200 | 80,000 | 78,200 |
| Fuel | 73,815 | 73,815 | 69,375 | 64,935 | 61,605 | 61 605 | 58,905 | 55,944 |
| Factory labor | 250,000 | 225,000 | 225,000 | 275,000 | 225,000 | 200,000 | 200,000 | 175,000 |
| Freight on finished product | 317,728 | 321,621 | 323,800 | 312,082 | 312,960 | 315,575 | 314,830 | 329,563 |
| Land rent | .... | .... | 4,000 | .... | .... | .... | .... | .... |
| Totals | 818,347 | 790,382 | 777,452 | 838,906 | 772,000 | 744,307 | 739,994 | 730,033 |

For brevity only the survey of the land found available at Boston is included in this paper. The results are found in Table 4.

## Variation in Factory Wages

From information available, common factory labor rates appeared to run about as follows:

| | |
|---|---|
| Norfolk | 35 cents per hour |
| Baltimore | 40 cents per hour |
| Philadelphia | 45 cents per hour |
| Wilmington | 40 cents per hour |
| New York | 55 cents per hour |
| New London | 45 cents per hour |
| Providence | 45 cents per hour |
| Boston | 50 cents per hour |

The payroll on the basis of Boston was estimated at $250,000 per year, and as all general factory labor in the various localities varied about in proportion to the common labor, the payrolls for the various districts were about as follows:

| | |
|---|---|
| Boston | $250,000 per year |
| Providence | $225,000 per year |
| New London | $225,000 per year |
| New York | $275,000 per year |
| Philadelphia | $225,000 per year |
| Wilmington | $200,000 per year |
| Baltimore | $200,000 per year |
| Norfolk | $175,000 per year |

## Summary

From Table 5 it seemed evident that Wilmington, Baltimore, and Norfolk warranted further study. Points south of Norfolk were ruled out as freight costs would rise very rapidly with no counterbalancing advantages. In fact, with general offices in New York City, it was felt that Norfolk was too far away. On the other hand, Baltimore, which was not much more than four hours of travel by train from New York, had a better skilled-labor market, and a more intensive study of this section disclosed a site superior to any of those that had been reviewed in the previous comparison. After the final check was made, Baltimore was chosen as the best location.

# Manufacturing and Wage-Payment Methods as Practiced by the Hall-Scott Motor Car Company

By ALFRED B. CELANDER,[1] OAKLAND, CALIF.

IN DESCRIBING the Hall-Scott practice of manufacturing parts for their engines, we shall start with the blueprint at the time it is approved and released for production.

The planning department, after ascertaining the quantity and daily requirements of a part in question, will work up the following details:

1 Lay out a line of operations, giving the shortest production path possible which is consistent with good practice.

2 Give operation number, name of operation, locating points for progressive tooling-up, name of machine most adaptable, number of machine, estimated time to perform operation, estimated minimum number of pieces per day.

3 Designate what special tools will be required, such as drill jigs, locating fixtures, piloted boring bars, reamers, form tools, and gages. The standard tools required, such as milling cutters, arbors, drills, reamers, and taps and spot facers are also listed.

4 Make rough sketches of such tools as must be made to conform to layout and time element of that particular part. These rough sketches convey to the tool designer later on the original idea of the tools as figured in layout, saving on designing time and standardizing the design of tools, an item in itself worth considering.

If the production warrants it, a "line-up" or a "gang" of machines will be arranged, taking the utmost care to machine the part in question properly. The time limit is set for the machine, and tools are designed in keeping with the quantities to be produced.

In laying out a line-up, it is essential so to dissect the work to be performed that operations of a similar nature, such as all milling and drilling, may be done in proper sequence with a forward movement toward the finish end of the line.

When an operation is necessarily slow, as, for instance, in a reverse-gear or chain housing, where several gear centers, bearing diameters, and shoulders must be bored and faced in one fixture, the time required to make one piece generally sets the maximum output of that particular line-up. If this maximum output is sufficient, then the following and shorter operations are done by one or several men following the work from one machine to the other to even up the time of the longest operation, thereby eliminating lost time and giving uninterrupted and continuous production.

Where one machine will not produce the required amount, it is practical to place two or more similar machines abreast in the line-up, and arrange for parts to be spread out to be conveniently handled by these several machines. After passing through this operation, the parts are again brought together and finished in a single line.

In the Hall-Scott plant each machine has its individual electric motor attached to or integral with it. This makes it possible to place the machine exactly where it is needed or to move it to a new location on a moment's notice should occasion, such as a material saving of time, so require.

[1] Plant Engineer, Hall-Scott Motor Car Company.

Presented at a meeting, May 31, 1928, of the San Francisco Section of The American Society of Mechanical Engineers.

It may seem a trivial matter to move a production part a few feet or to the next aisle for the next operation, but as a matter of fact, this is wasted time and in many cases requires more time than is actually required to do the work.

We find the line-up method, if organized properly, to be, in many respects, the ideal way of manufacturing for the following reasons:

It stimulates the operator to do his best to keep up his part of the work.

It breaks the monotony of the work, as the workman in most cases performs several operations and is kept busy arranging his work.

It serves to eliminate spoilage, as the workman is doing the same thing over and over again and quickly detects any irregularity in the part.

It tends to improve workmanship, as each man is made to understand that he is responsible for everything passed by him.

It tends to act as a check on itself, as jigs and fixtures are used, wherever possible, which locate the part by the previous operation and thus prove and lessen inspection.

It saves inspection time, as line inspectors are provided with suitable inspection tools. The final inspection may, in many cases, be eliminated, and the part moved directly to the assembly line, or stock, as case may be, reducing chances for breakage and damage to parts in transit between operations and departments, in this case saving non-production labor and floor space.

The mechanical handling of parts is well organized at the Hall-Scott plant. The rough materials, after being inspected, are placed on platforms or in boxes and are distributed throughout the plant by electric lift trucks. In the line-ups the roller type of conveyor is standard if the part is too heavy to be easily lifted. For the lighter parts, as, for instance, the piston and connecting-rod line-ups, special chutes are provided to slide parts from one operation to the next. For still heavier parts and for parts that will not slide or roll, there are jib cranes and overhead monorails from which are suspended various lifting units, with air hoists predominating. Compressed-air hose for cleaning out jigs and fixtures are suspended on counterbalances within reach of the operator, but out of the way of oil and the part in production. Nut drivers and stud setters, both pneumatic and electric, are also counterbalanced. In heavy-duty work they are attached to sliding members to protect the operator from injury.

Inspection is very rapid, and limit gages of a heavy type set the go and no-go.

Cleanliness is essential on all parts and is effectively handled in splash or spray washing machines of the link-conveyor type.

Painting is done by means of a spray over down-draft exhaust grates. With this system it is not necessary for the painter to breathe through the customary wet sponge. In the old spray-booth system the painter had to work in the fumes or fog-like mist of the poisonous and explosive gases from the paint, which endangered himself and surroundings. In the down-draft system these fumes are drawn downward through grates and

out of the building, never having time to settle, and thus gas pockets and accumulations of paint around the spray booth are eliminated. These grates are easily removed for cleaning. The pits have sewer connections and are washed out regularly. The doing away with the sponge alone has saved a lot of time, as proper care had to be given to it regularly.

The laboratory makes a chemical analysis of all materials used, and it also gives a complete physical-property test to all heat-treated parts.

There are two dynamometer rooms at the plant, in one of which there is a 400-hp. a-c. dynamometer and in the other a 300-hp. Sprague electric dynamometer. Engines are given a final run, adjustment, and performance test to determine accurately that they are in all respects up to specifications.

### Incentive Wage-Payment System

In order to establish uniform costs for various parts, an incentive wage-payment system has been adopted which is cutting down production variations to a minimum.

The system used at the Hall-Scott plant is not built on the basis of speeding up machinery to a point which will shorten the cutting life of tools and possibly endanger the quality of the product. On the contrary, it was found, after a careful study of the situation, that the biggest factor to be dealt with was the time which was lost by the operator between the handling of successive pieces of work. In many cases this lost time exceeded the actual working time.

It was found that several factors might account for this lost time. One of these was the placing of materials so that they were unhandy for the operator to reach, causing undue fatigue and possibly creating a tendency toward carelessness. Another was that quite often the parts being worked upon would not fit the jigs or fixtures properly, making it hard to set and replace the work. These faults corrected, still another was found which was probably the most common, indirect cause of this lost time. This was lack of interest in the work to counteract the monotony of repetition. With this in mind a method was sought of adding an incentive for the workman which would benefit both himself and the company.

As a basis on which to work it was decided to find the net time required by a good man to perform any operation, at a speed guaranteeing good quality with the best tools available, and done on a machine assigned to do the work. For performance in this time the company would allow an incentive pay of $1^1/_4$ times that for the time consumed. To this net time was given the name of "best time" per piece, which, if kept up throughout the day would give a maximum production under the most favorable conditions. But as a maximum standard would tend to hold down production, it was considered best not to use this expression, so that it is employed only for calculations in arriving at the results of problems.

It was found more desirable to establish a minimum number of pieces that an ordinary operator should turn out in a standard 8-hour day. This minimum number of pieces was set at 75 per cent of the maximum. For this the operator was allowed his day rate. The time it takes to make one minimum piece is called "standard time." Standard time gives the standard cost of operation. For every piece made above minimum, a bonus of 75 per cent of the standard cost is allowed as an incentive.

As each individual operation must be analyzed and treated by itself, there has been developed a sheet called the "time-study record." On this form, the time-study man records all characteristics, incidentals, and a step-by-step analysis of speeds, feeds, cuts, and special tools, if any, used in arriving at the observed time on the several pieces. From this the best time is determined. By adding 33.3 per cent for tooling and contingencies the standard time is obtained. Standard time multiplied by hourly rate would give standard cost; but as day rates vary, two standard day rates have been established, one of $4.80 to apply on all operators under $6 per day, and $6 for operators receiving $6 or more. This makes the full bonus respectively $1.20 and $1.50, or 25 per cent of the two standard day rates. This gives the operator rated at $4.80, $6 per day, and the $6 operator, $7.50, when the full number of bonus pieces is made, which is always possible if all time between pieces is accounted for and utilized and if no undue tool trouble occurs.

A route card is issued in duplicate by the production department, giving the number of the department to do the work, the operation, the set-up time, the minimum number of pieces, and the bonus rate. The original is given to the department foreman and the manila-card duplicate is slipped into a celluloid container and follows the material until the job is finished.

In starting a new job lot the set-up time must be taken into account. This is also given on the time-study record and is the longest time it should take to get a machine or job under way. If the foreman finds that the job requires less time for set up than is stated on his production order, he will write in what time he allows on the next job card which is issued to the man who is to do this particular operation. The operator turns in the next job card to the timekeeper and receives his operator's job card with clocked time of starting the job and other information needed, such as set-up time, minimum pieces, and bonus rate.

This system applies as well to groups as it does to individuals. Take for instance the case of the connecting rod and its cap. Both of these have been produced on the bonus plan for three months or more. The rod goes through 22 machining operations in a line of machine tools with a group of seven men. Each man attends to from 3 to 4 operations, thus dividing up the work equally. The best time is 0.03333 hr. and the standard time is 0.04444 hr. The hourly rate for this class of workman is $0.60, making the standard labor cost per operation $0.02667. Hence the minimum for 180 pieces is $4.80. Taking the last three days' output of this particular part as 234, 236, and 238, or an average of 236, and subtracting the minimum of 180, there are left 56 pieces for which the men are entitled to a bonus. Seventy-five per cent of the standard cost of $0.02667 is $0.02, which is the bonus on 56 pieces, or $1.12 bonus money to be added to each man's day rate. The total earnings of these seven men on May 8 were as follows:

| | | | |
|---|---|---|---|
| Clock No. 20, day rate | $4.80 plus bonus | $1.12 = | $5.92 |
| Clock No. 21, day rate | 4.40 plus bonus | 1.12 = | 5.52 |
| Clock No. 34, day rate | 5.44 plus bonus | 1.12 = | 6.56 |
| Clock No. 77, day rate | 6.00 plus bonus | 1.12 = | 7.12 |
| Clock No. 93, day rate | 5.54 plus bonus | 1.12 = | 6.66 |
| Clock No. 94, day rate | 4.00 plus bonus | 1.12 = | 5.12 |
| Clock No. 212, day rate | 3.64 plus bonus | 1.12 = | 4.76 |
| Total for machining 236 rods............ | | | $41.66 |

In dividing cost by rods made the result is $0.1765 for the seven men's work per rod ready for assembly. The last previous day-work record showed a cost of $0.5134 per rod, which is 190 per cent higher than the present cost.

The cap for the connecting rod in question is made in a separate line-up. There are nine operations and three operators. The best time is 0.03167 hr. The standard time is 0.04222 hr. The standard cost is $0.02534 × 3 operators, which amounts to $0.07602 per cap ready for assembly. The last previous day-work cost was $0.2623, or 245 per cent higher than the present cost.

There is another advantage of this line-up and bonus pay that might be worth pointing out. Let us suppose that we start this line with seven men. At first every one is busy keeping his allotted machines going, but after everything is running smoothly each man finds time to do a little more, so that eventually the crew can be reduced to six men. This does not alter the time-study record materially, but just rearranges the operators and pays six instead of seven men, saving one-seventh of the cost.

When the bonus payment system is completely installed, it will be possible to tell, not alone the labor cost of the parts, but also the exact amount of individual machine time necessary for a given number of motors per day. This, in turn, will govern the number of men required in the production departments, and it will also show whether it will be necessary to work overtime on any machines in order to meet production requirements.

To facilitate the work of the time-study man, a set of tables has been worked out. One gives the seconds and minutes consecutively from 1 to 60, converted into decimals of one hour. Another gives the bonus rate to minimum pieces from 1 to 200. In order to distinguish the lower bonus rate from the higher, the latter is prefixed with a zero, making it permanent and always to be written that way. For instance, the bonus rate of 019 = $0.23684 gives the higher rate as against the bonus rate of 19 = $0.18947 for the lower.

The contention that spoilage is kept to a minimum with the line-up and bonus payment system was upheld on a check of 1143 connecting rods that were finished on May 10. The first operator lost three by misplacing them in one of the milling fixtures, the third man misplaced two in a drill jig and one in straddle-milling operation, a total of six spoiled and 1137 passing. It will be noticed that five men out of this seven-man line never missed once, and in all but one instance caught the spoiled rod on the next operation. This is about half of one per cent spoilage, which must be considered good.

## Discussion

Arthur B. Domonoske.[2] The paper comments on the speeding-up effect of the work on the conveyor coming to the operator, but the writer believes that the work leaving the man has as favorable psychological effect on him as the pieces coming to him. Any observing stockchaser soon learns to remove rush jobs from the vicinity of the workman as soon as they are completed, even if the need of haste no longer exists. In the line, the workman actually sees the work on the way to the next station and also notes how urgently it is needed. This may result in spurts of speed at the time most vital to keep the line going when otherwise delay might arise from lack of parts.

Several questions occurred to the writer in reading the section on the bonus system, as:

There are two standard day rates, $4.80 and $6.00, with a possible bonus on the connecting-rod job of $0.02 and $0.025 per piece respectively. In the table shown, the $6 man receives the same bonus as the $4.80. In general, would the $6 man in the $4.80 line receive the higher bonus or the bonus common to the group?

When the shop is completely changed to the bonus system, will the foremen of the departments receive additional compensation? The writer has noticed much discontent among set-up men on automatics, where the operators were able to earn good money on piece rates while the men responsible for the set-up were paid day rates.

[2] Executive Head, Mechanical Engineering Department, Stanford University, Calif. Assoc-Mem. A.S.M.E.

Although not mentioned in the paper, what provision is made for machine repair? Does the company rebuild or have some other firm rebuild machine tools? In other words, is it economical to rebuild an old machine or would scrapping be better?

S. S. Jacobs.[3] Before proceeding with the discussion or any details concerning this particular production system, it might not be amiss to check up to see what a production system should consist of basically.

### Basic Production Units

The following broad divisions into which production work might be grouped will take care of all major requirements:

1 A proper detail blueprint to contain all necessary information and dimensions, properly toleranced material and its treatment, tooling record, and change record

2 A planning department to decide operations and their sequence, and also time study and rate setting where used

3 A production department to see that necessary materials are ordered and that the planned program is carried out by a follow-up system

4 A properly balanced manufacturing organization

5 An efficient inspection system to maintain the necessary quality and accuracy standards of the degree of interchangeability and accuracy necessary

6 A cost-finding and audit division.

The Hall-Scott system as outlined in the paper presented seems to cover the production requisites as outlined and shows a well-balanced organization. Production systems have proved their merits in cost cutting, increasing output, while still maintaining quality and interchangeability. They must, however, be custom-made to suit each individual business. The system which functions perfectly in one plant might be very inefficient in another. There are several interesting production applications in the description of the Hall-Scott system. One of them is the application of straight-line production, and the other, the application of the bonus system.

### Straight-Line Production

In discussing straight-line production, it is of course obvious that a fairly large quantity of parts, and reasonably continuous manufacture, would have to be present in order to use the method advantageously. As an example: A connecting rod of which 1143 parts were manufactured, cost 26 cents each, or a total of approximately $297. This line would need a fairly permanent set-up and continuous operation or there would be a considerable increase in cost. The set-up and tear-down cost of tools for this $297 worth of work would be rather high for this output if interrupted before complete. Very often, on the other hand, if there were not sufficient work for continuous operation, the cost of machinery standing idle in the straight-line method would not be economical, if not used for other parts.

### Service to Customer

The problem of service and parts supplied to customers also enters into this plan. It is not always possible or economical to carry too large a stock of service parts. If the stock gets below the level, any manufacturing of service parts will probably interfere with a straight-line system of producing parts for a regular run of machines. If an emergency order for parts which had to be rushed were received, it would upset the predetermined planning program on a straight production line where the machines are grouped in the proper sequence for the manufacturing or assembly

[3] Chief Draftsman, American Can Company, San Francisco, Calif. Mem. A.S.M.E.

of units. These extra parts are sometimes taken care of by overtime or extra shifts. Neither method is always economical where parts are sold by pre-set catalog price and figured on regular production-cost basis.

### Flexibility in Forming Machine Line-up

While flexibility in tool placement and arrangement seems an ideal scheme, the majority of production tools today are very heavy. They require good foundations which are permanent, to meet modern production demands. It is rather difficult to have most production machinery, even though motor-driven, taken from place to place and arranged with very little time elapsing before machine is ready for production.

While considerable time is undoubtedly lost in transferring work from machine to machine and from operation to operation, this can be reduced to a rather small figure by modern means of transportation. In a concern where a great many parts and a good many different machines are manufactured in rather small quantities, it is a difficult matter to group machines unless the amount of equipment is increased. In place of this investment in extra equipment, the money could be invested in quick transportation units, either mobile in character, such as hand or electric trucks, or stationary permanent units, such as roller conveyors, elevators, and the like.

The author mentioned the use of as many of these modern methods of part transportation, along with the straight-line units, as seemed feasible. It seems improbable, however, that beyond such machines as light lathes, drills, etc., most of the major heavy machines in modern manufacturing could, as now designed, be moved around at a moment's notice. If such machines, mobile in character, were made, they would be of the lighter variety or perhaps of special design for special-purpose work.

Opposed to this idea of straight-line manufacture, the same class of machines might be distributed in unit lines, in various parts of the plant in a machine-group plan. This consists of placing each group of similar tools as a unit with a trained foreman in charge of each group. One foreman is in charge of mills, another one, of drills, another, planers, etc., and this makes for considerable efficiency in both foreman and operators in each department. The benefits of this group system are entirely lost in a straight-line set-up.

### Straight-Time and Bonus-System Work

The second major item of interest in the paper presented is the development of a special bonus system. Again, the matter of quantity production comes to the fore. Where parts are not made in quantity, the economy of bonus or premium system is questionable. This has been proved in the concern with which the writer is connected and in which four of the Eastern manufacturing plants operate under the premium system as against the San Francisco plant which operates on day labor. In San Francisco with a greater variation in the number of parts manufactured per employee, the production quantity per part does not warrant the overhead expense involved. The larger quantities manufactured at the Eastern plants allow sufficient leeway for extra cost of clerical work necessary for bonus or premium pay. The premium method seems to be a better system, however, than either day work or straight-line work as used by Hall Scott Co., and offers a solution of rate setting for both the fast and slow man.

For the shop where premium-system overhead is too great, may be mentioned the matter of foremanship. The alert high-class foreman goes a long way to offset, in a straight-day-work-payment shop, the gain which is made in other plants by using the premium system, it being understood, however, that a production system is followed in both cases and work is planned.

As an example: In the San Francisco plant of the American Can Co., which is without a premium system, but where work is planned, and where the tooling is equal to that of the Eastern shops using the premium system, the costs have been practically the same when from ten to one hundred pieces were produced at one setting. When the number of parts increased from 250 to 1000 at one setting, the effect of the premium system is noted. The quantity of parts allows a man a chance to get the swing of work and the handling of tools, and parts are produced faster as the work progresses, so that naturally the cost is reduced with practically no rise in spoilage percentage. The key to this whole subject is undoubtedly sufficient quantity. Just where the line may be drawn as to what quantity, and with what tooling, premium work would have its best effect, is a rather hard thing to determine. It must be worked out for each individual concern according to its needs.

The paper states that the bonus system has been installed with practically no extra clerical work involved. It would seem rather a difficult matter to install time study, rate setting for bonuses, and continuous adjustment of these from time to time without additional clerks, study men, and the systematic gathering, recording, and revising of data for a shop producing large quantities. This additional overhead, if it develops, is soon absorbed in the profitable results obtained. A shop producing small quantities of each part would probably find this system too detailed for profit showing.

The standard of foremanship is becoming more and more an important function in manufacturing procedure. This is particularly true where a variety of production parts must be manufactured in relatively small numbers. The foreman thus becomes the key figure in an operating or production system, rather than the individual urge of each mechanic due to any bonus or premium system. While a straight-line set-up, as described in this article, is an excellent one where it can be applied, the application can only be ideal in a relatively small number of plants. The average number of men, according to statistics, employed in manufacturing plants, is under a hundred men per plant in the U. S. As there are many large Eastern units employing thousands of men in one plant, it can readily be seen that there must be hundreds of small plants to a few large ones. The total production of the small plants amounts to an enormous figure, and with the ordinary man purchasing these productions and paying, in the cost, all the inefficiencies which exist in small plants, it seems that the necessity for a production system adaptable to small organizations is just as necessary as such methods as are described in this article which are applicable to only fairly large units.

At this point it might be stated that there are a great many large manufacturing plants which do not find it economical, because of the size of production machinery and other features, to use straight-line methods.

The writer's personal observations of a considerable number of Eastern plants, such as machine-tool builders, were that only a few of the units are given what might be called straight-line manufacturing progress to a given assembly point. The method of manufacturing eight or ten parts in gang machining is used in preference to manufacturing single parts in a straight process. Under this system of group machinery rather than straight-line process, the piecework system is used perhaps more than the premium. Each operator working on an individual machine is responsible only for what he produces, and the speed of an operator behind or in front of him has no effect on the amount of work which the individual can produce.

### Corrections and Rejections

No mention was noticed in the article as to methods of handling

corrected and rejected parts. The higher the degree of interchangeability and quantity demanded, the greater the percentage of corrections and rejections. This will be so whether inspection is automatic by checking jigs or personal by inspection gaging. This would also be so whether inspection is for each operation or only the finished work.

Corrections and rejections may be brought down to a minimum, but they can never be entirely eliminated. They must be considered in any bonus system. The division of the losses in such parts between employee and employer is usually a sensitive matter. While the method of adjusting in the Hall-Scott system is unknown to the writer, he feels that the giving of a bonus of 75 per cent of time only for work over standard time is very liberal, and he wonders if the spoilage and correction adjustments are taken out of this time of employee or are absorbed by the company.

Another matter of vital importance in such systems is the effect on men not directly making parts but indirectly responsible for speed of work produced by premium-receiving employees. If the foreman is not allowed a premium in proportion to the men in his charge, the best results cannot be expected. If the men supplying material, treating material, etc. are not considered in such a system, there will be possible lapses of efficiency in system.

At this time the writer would like to outline a system which includes consideration of all persons concerned in producing parts at a rate above standard, and who ought to receive some consideration from results obtained over standard. This system consists of, first, a standard cost set on each operation, the rate to be set in hours or tenths of hours rather than in dollars and cents. Thus, the time cards and payroll for any employee, irrespective of his day rate, can be easily balanced. Second, penalty time is deducted from the time saved according to the pieces corrected and rejected in lot manufacture. The premium is figured by taking actual lapsed time for a job, divided by the total number of pieces, and to this lapsed time is added penalty time for corrected and rejected pieces. This, subtracted from standard time, gives the premium time allowed. An example of this would be as follows:

Suppose that out of 100 pieces made, 87 were good, 10 were corrected, and 3 were rejected, and the total time worked on original pieces was 75 hr. This represents 0.75 hr. each. The penalty time would be 13 pieces multiplied by 0.75 hr. which equals 9.8 hr. actual time. Seventy-five hours plus 9.8 hr. penalty time gives 84.8 hr. gross elapsed time. If the standard time were one hour each, the 87 pieces would take 87 hr. The allowance for corrected pieces plus the 87 good is 84.8; a total saving of 2.2 hr. for which premium would be allowed on the job.

The premium is divided so that 50 per cent goes to the employee directly making parts and 50 per cent to the company. The company in turn takes 20 per cent of its portion and places it in a so-called premium fund. This fund is divided among those persons in the plant who are in a position to increase production through direction or supervision, called class "A" employees. On the other hand, other indirect employees, such as those furnishing material, tools, power, or facilitating the progress of the work, would be classed as "B" group. In a system of this kind, it is obvious that executives, engineers, production men, inspectors, premium clerks, etc. could not participate in premiums.

The premium fund is divided as follows: 80 per cent of fund is given to class "A" group and 20 per cent to class "B." The total fund allowed to each group is divided by the number of men in each group participating, each receiving an equal share. Class "A" group consists of foremen, assistants directly supervising producing employees who receive 80 per cent of bonus fund. The "B" group consists of indirect foremen, such as pattern-shop, heat-treating, and tool-room foremen, etc., and such men as casting clerk, chief stock keeper, electrician, millwright, etc.

It can be readily seen that in such a system everybody concerned from the man handling the raw material to the man working on it participates in the premium and that a unified spirit of speed and production is produced. As an example of the average premium rates which can be earned, the following figures may be of interest. The premiums in four plants located in various parts of the United States vary from 4 cents an hour to 11 cents an hour in addition to standard wage, or from 5 per cent to 17 per cent. The department foreman in one month might average around $50 in additional wages on a premium basis, while the class "B" group participants average from $7 to $24 a month extra. These amounts are well worth while when one considers that the average standard rate paid is reasonably close to the day rate paid by some other plants.

### Author's Closure

Our bonus system, as started a year ago, is gradually working its way through all machine departments. So far we have found no serious obstacle in applying it. We have operations on parts that will take a whole day to perform and other parts of which 3584 pieces are finished in one day, with bonus applied just as efficiently with lots ranging from 25 pieces to a continuous run.

It is true that any system, in order to function, must be more or less "custom-made" in order to fit into the various lines of business; but the principle remaining is the same, therefore it can be readily applied.

As to our bonus rate: If a $6 a day man is temporarily in a lower bonus line-up, as it happened in the connecting-rod line at the time in question, he is paid the low bonus rate, but if it is a permanent job for a high-priced man, he gets the high bonus. Our additional clerical help on bonus costs less than 3 per cent.

As to rearranging line-ups, we do not hesitate in switching machines about, be they heavy or light, if production benefits by it. The only machines placed permanently are large Ingersoll milling machines and the largest sizes of boring mills. These machines are generally placed and the line-ups are laid out accordingly. The floors are heavy enough to carry all others without a special foundation.

As to toolsetters and foremen participating in bonus, the point may be well taken, especially in factories where their earnings are less than those of the man on bonus, but, may I say this. We have had the heartiest cooperation of everyone, men and foremen alike. The chief aim of all has been to bring the output up to meet time allowed without sacrificing quality.

Seventy-five per cent of standard cost paid in bonus on all pieces above minimum leaves 25 per cent which may be accumulated and used to advantage, in paying the cost of the system, a participating bonus, or new tools, as the management may decide.

Hall-Scott maintains a machine-repair and rebuilding department. If a machine is not suitable for one job a place for it can always be found on a single-purpose job where it will do as good work as a new high-priced machine would do.

# Motion-Study Principles and Their Application in a Department Store

By B. EUGENIA LIES[1] AND MARIE P. SEALY,[2] NEW YORK, N. Y.

*The fundamental principles of motion study are first presented, and are subsequently illustrated in the report of a study which was made of a centralized cashiering system in the department store of R. H. Macy & Co., Inc., New York.*

*After defining motion study and stating its benefits to worker, employer, and community, the authors describe the methods used by the motion-study analyst in attacking the problem of finding the best method of doing a particular job. The complete data relating to the job, the worker, and the environment are first collected. The sequence of operations involved in the job and related to it are recorded in a process chart, and in some cases a micromotion study is made, the actions of the worker being recorded on a motion-picture film. Placed in the scene is a special clock which shows the time to $^1/_{1000}$ of a minute, and thus makes it possible not only to study the motions, but to time them accurately. From these films, a simultaneous motion cycle chart is prepared. The data and records thus obtained in the preliminary study of the present method are used as a basis for making changes which will increase productivity, reduce fatigue, and save time. From these studies, the best method of doing the job is evolved. Tasks and rates can now be set and incentives established.*

*The case illustrating the principles described is presented in the second part of the paper. The factors affecting the work of the cashier are summarized and the results of the motion study discussed. Examples of the process and simultaneous motion cycle charts are given. The changes which were made in the working equipment, the work room, and the work of the cashiers are described, and the benefits which have resulted from the careful analysis are explained.*

Motion study is a method of analyzing work in order to eliminate needless, ill-directed, and ineffective effort, and the resulting unnecessary fatigue, and to utilize the necessary effort in the most economical way. It benefits the worker by placing the best-adapted worker on the job, by eliminating fatigue, and by increasing earnings; it benefits the employer by increasing production and decreasing unit costs; and it benefits the community by providing lower-priced commodities, greater purchasing power, and better-adapted and better-satisfied members of society.

## Method and Technique of Motion Study

"Motion study consists of dividing work into the most fundamental elements possible; studying these elements separately and in relation to one another; and from these studied elements, when timed, building methods of least waste." (Gilbreth, "Applied Motion Study," p. 48.) "The variables which must be studied in analyzing any motion group themselves naturally into the following divisions: (1) variables of the worker; (2) variables of the surroundings, equipment, and tools; (3) variables of the motion." (Gilbreth, "Motion Study," pp. 6 and 7.) "The accurate measurements involved in getting the best results include three elements. We must determine first the units to be measured; second, the methods to be used; and, third, the devices to be used." (Gilbreth, "Applied Motion Study," p. 44.) These devices should be as refined as necessary to get the best results, considering also how much time and money may be justified by the expected results.

The method employed by motion study includes, first, recording present conditions and practice. Under "conditions," the survey includes the surroundings of the worker, such as the lighting, ventilation, dust, temperature, humidity, odors, noise, etc. The work place and its relation to the worker are also studied, that is, the equipment used, such as desk or bench, chairs, etc., and also the tools and devices used. The work done is recorded in detail. For this purpose the process chart is used, and, in some cases, micromotion study. Both of these devices and their uses are discussed later in detail.

All other data relating to the job such as flow of work, peaks in business, records of past production, cost records, etc., are also gathered, as well as data concerning the worker, including the physical, psychological, and psychiatric factors influencing his work on the job. Information on age, sex, schooling, physical conditions, personality traits, and ratings on intelligence and psychological tests are included in the worker's record.

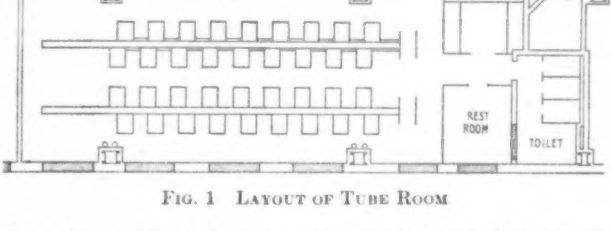


Fig. 1 Layout of Tube Room

## Other Steps of Method

After present conditions and practice have been recorded, the next step is to analyze the data, considering such points as the following:

(1) Is the work necessary? Does it contain any unnecessary elements, operations, or "therbligs?"[3]
- *a* Can these be eliminated entirely because they are useless?
- *b* Can they be eliminated by combination, substitution, etc.?

(2) *a* Can the necessary work be done with less expenditure of effort?
- *b* Is the arrangement of work, materials, and tools within the normal grasp area?[4]
- *c* Is the routing and scheduling most direct, providing continuous work, etc.?

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[2] Assistant Director of Planning, R. H. Macy & Co., Inc.

Contributed by the Management Division and presented at a meeting, New York, N. Y., January 30, 1928, of the Metropolitan Section of The American Society of Mechanical Engineers.

[3] Gilbreth divided all operations into 17 elements of a cycle of motions which he called "therbligs." See "Management's Handbook," p. 809.

[4] Work done by Piacitelli and Allen (*Manufacturing Industries*, July, 1927) and Moeda and Lossagk in Germany has developed data on the normal grasp area and the best working area.

*d* Can improvements which will reduce fatigue be made in the surroundings of the worker?

Through the analysis of the data, possibility methods are developed, and finally the ideal solution is determined, including the best methods, the best conditions, and the best type of worker. However, the ideal solution may not be the one actually installed, since limiting factors, such as the cost of new equipment compared with possible savings, may force deviations from the ideal. The solution decided upon, however, must be the best practical solution, considering all of the factors in the situation. Developing the ideal solution is, however, desirable and essential even though it may not be installed in toto.

After the conditions and methods are standardized, the task can be set and an incentive plan decided upon. Then the problem of maintenance of the standard methods always arises, and for this purpose standing orders and instruction cards are used.

### Devices Used Depend Upon Problem

When the motion-study analyst is beginning an investigation, he decides how much and what elements of his technique he must use on the particular job. The character of the job decides this question. At times only a process chart will be necessary. On other more complicated jobs a micromotion study involving the use of motion pictures may be needed.

### Process Charts

Process charts are used to record in a simple compact form and to visualize the elements of a process in sequence and in relation to the entire process. They record present practice for the purpose of studying and analyzing the present practice, and also serve in visualizing possibility processes which improve the present practice by (1) changing the sequence of elements, (2) eliminating elements, (3) combining elements, and (4) substituting or changing elements.

As a record of standard practice, the process chart serves as an authoritative and complete picture of the entire process. It is particularly useful as a teaching device and as a means of maintenance.

At the top of a process chart there is usually a plan of the work place, with the arrangement of equipment and tools. The chart itself is made up of a series of symbols, connected by lines, indicating the sequence of operations and also the relationship of those operations, such as alternatives of process, separation of units, and combination of units. Such a chart, prepared in connection with the case illustrated in this paper, will be found in condensed form in Fig. 2. The symbols indicate:

(1) What—that is, materials and supplies, operation inspection, movement, storage of materials and supplies
(2) How—that is, word description next to symbol
(3) Who—name of job or mnemonic job symbol
(4) Where—work places, work rooms, etc.
(5) When—that is, sequence or if a definite time, in description next to symbol.

The "why" element is obtained by the analyst in his study of the chart.

### Micromotion Study

The other particular device used by the motion-study analyst is the micromotion study. By this method, a motion picture is taken of the worker at his work place with a clock included in the picture. A record is thus made of the method used, the time taken, and all the surrounding conditions (except sound).


Fig. 2 Portion of Process Chart Including Some of the Operations Performed by the Cashier

The data on the film may be studied at any convenient time and shown graphically on a simultaneous motion cycle chart, known as a "simo" chart, a sample of which is illustrated in Fig. 3. Such a chart indicates horizontally the parts of the body used and vertically the time consumed by each element of motion or therblig. The time is shown in units of $^1/_{1000}$ of a minute, which is possible because the clock included in the picture registers time in this small unit. As the data are taken from the film, the motions are split up into therbligs. Each of the 17 therbligs is shown in an individual color, so that it is possible to see from the chart the exact therbligs used and the time consumed by each.

By comparing the therblig analyses of all the methods used, the analyst can easily compare the differences in the various methods and can evaluate each. He is then able to complete his analysis and synthesize the best arrangement of therbligs into the best method.

### Value of Motion Study

Analyzing work by means of the principles and technique described above has the following advantages:

1 In the first place, this method considers every element influencing the work and thus effects improvements in every factor, that is, the surroundings, the equipment and tools, the method, the worker, and thus the time.

2 Motions are recorded as well as time, and thus the data on time are of real value.

3 In addition, this is the only method by which it is possible to analyze adequately operations involving short cycles or very rapid movements, since the elements of this type of work cannot be studied as accurately by the stop-watch method. Analyzing this type of work is very important, as often enormous savings can be made both in unit cost and in fatigue by analyzing these short-cycle or rapid-movement operations.

4 These devices are also valuable in studying a group of workers. It is, indeed, the best method to record what each worker is doing simultaneously when a group works jointly on an operation.

5 This method also has a decided advantage in recording the standard method as well as standard time. This is particularly valuable in setting a task.

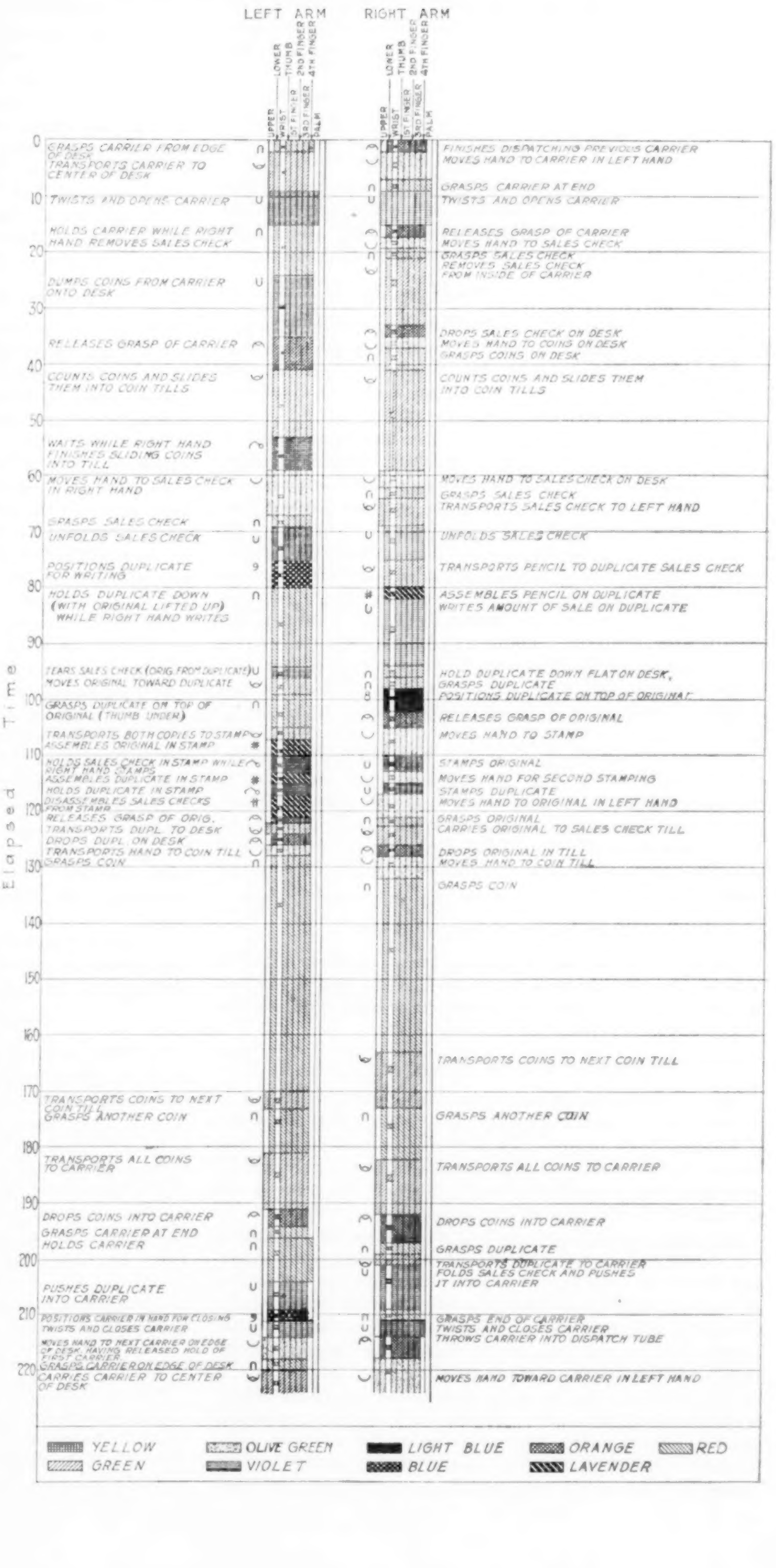


Fig. 3 Simultaneous Motion Cycle Chart

6 As a means of training the analyst himself, this method forces attention on all phases of a problem, develops a logical analysis of the job, and also develops keen observation in the elements of motion.

7 This method also permits recording times of fundamental motions or therbligs. This is important in building up standard times, when the elemental times are considered in relation to the variables.

8 As a means of training the worker, the micromotion produces acquisition of skill in a minimum time; first, by training in motions and thus developing habits of correct motions from the start; and, second, by providing a visual record of what is to be done.

### Application of Motion Study in Retail Field

Turning to a definite field, we find that the principles of motion study can be applied in the retail or distributing field as well as in the factory. This has, indeed, been done by R. H. Macy & Co., Inc., a retail department store in New York City, in order to perfect methods and systems, and to set tasks.

The technique, moreover, has been used on a large variety of jobs. It was used, for example, in analyzing conditions existing in the fur-storage department which receives coats from customers in the spring, stores them in cold vaults, and then delivers them to customers when wanted, usually in the fall. The entire work of the department is concentrated in a few weeks in the fall and spring. The fur-storage problem was largely one of determining the simplest, most direct, and most economical routing for the handling of the furs and the records involved; scheduling the work to take care of a tremendous peak, which lasts only a few weeks; providing the best methods for each job so that high production can be made on each job and, in addition, so that definite training can be given and the duties of each job learned in a minimum time.

The method has also been used in the furniture warehouse, in arranging stock in some of the selling departments, and in standardizing methods and setting tasks in correspondence, typing, and depositors' accounts (banking) departments. To illustrate the principles of motion study, the details of the method as applied to the analysis of the problems existing in the central cashiering department will be presented.

### Purpose of Cashiering Study

The study of the cashiering department was undertaken in order to improve the service to customers and also to decrease the operating costs of the tube rooms by increasing the production of the workers.

### Description of Department and Work

The tube rooms are the units of a centralized cashiering system to which the money received from the customer and two copies of the sales check are sent in carriers via pneumatic tubes. The carriers fall on a belt conveyor and are carried to the cashiers who sit at desks on either side of the belts. Fig. 1 shows the arrangement of one of these tube rooms.

The cashier grasps the carrier from the belt, opens it, withdraws the money and sales check from the carrier, counts the money and checks the arithmetic of the sales check, stamps both copies of the sales check, retains one copy, but places the other with the change in the carrier. She then dispatches the carrier by placing it into a tube from which it falls on to a lower belt conveyor which carries it to the switcher at the end of the belt.

The switcher sends the carrier back to the department where it is given to the sales clerk. In the meantime, the merchandise checker, located in the department where the sale was made, has been wrapping the package, so that both the package and the change are now ready for the sales clerk to give to the customer.

### Conditions Before the Study

Before the study was made, a bonus plan had been in operation in the tube rooms for several years. With this incentive, an increase in production had been obtained. Indeed, some of the cashiers had become very skilled in methods which each one had developed for herself, and had developed a high average production. The average production of most of the cashiers was quite low, however, and the time required for a new cashier to become skilled was from 3 to 4 months. This was a decided handicap at the time of the Christmas peak, because there was a possibility of giving very poor service to customers unless new cashiers were hired long before the peak actually arrived.

### Recording Present Conditions and Practice

The first step in the study was to record present conditions and practice. A survey of the surrounding conditions included the lighting, ventilation, noise, and vibrations.

Desk lamps on each cashier's desk illuminated part of the working area of the desk as much as 50 foot-candles (directly under the lamp), with variations down to 20 and 10 foot-candles on different parts of the desk. The general illumination of the room, however, ranged around 4 foot-candles, with parts of the room, especially the end and the corners, in deep shadows. The contrast between the brilliantly lighted spots on the desks and the meagerly lighted surroundings made the cashier adjust her eyes to the difference every time she raised or lowered them. This situation contributed to the fatigue of the cashiers.

The ventilation was good in all of the tube rooms except the one nearest the street. Here the dust from the street was so bad that it was out of the question to keep the windows open.

Nothing had been done to eliminate the noise caused by the vibrations of the air drums of the tubes and the whirring of the motors moving the belts. The noise was deafening, so much so that the ringing of the telephone, which was almost continuous, was scarcely heard.

The vibration of the floor of one of the tube rooms presented a very annoying problem. This tube room is over the engine room, in which the steam pipes were hanging from the ceiling directly under the floor of the tube room. The result was a constant quivering of the floor to which it was difficult to become accustomed.

The general layout and routing of work in the tube rooms had been previously studied, and after restudying the situation, it was decided that the present layout was the most desirable one.

### Work-Place Equipment

The work place and the equipment, however, were also studied in detail. The layout of the desk was studied in connection with the motions involved in the transaction, as will be discussed later. The old desks were 38 in. high, a little too high for comfortable working when the cashier was standing, but the desks were made that height to accommodate the height of the top belt. High chairs were used also, but these were of the swivel type on which the seat and back rest tilted backward and on which a circular hoop about 10 in. from the floor served as a foot rest. The chair was so awkward that the cashiers sat only on the front edge, with no support for the back and in a very strained and fatiguing position. The equipment—the cashier's stamp, the carriers, crayon pencil, etc.—was also studied.

### Record of Work Done

The work done in handling a tube-room transaction was recorded by means of a process chart, a portion of which is shown in Fig. 2. The entire process was recorded from the point at which the sales clerk writes the sales check and receives the money from the customer, and the transaction is followed through the

work done by the merchandise checker and sales clerk until the change and package are handed to the customer.[4] The complete process was thus charted in order to avoid the danger of later making changes in the cashier's work which would interfere with the work preceding or following the cashier's operations.

The operations most directly relating to change making, that is, the operations of the cashiers, were studied more closely by means of the micromotion film.

Motion pictures were taken of five cashiers. In order to determine which cashiers were to be filmed, the motions of all cashiers were observed and the psychological factors influencing their work were considered, as well as their production over a period of six months. All of these factors were considered in deciding upon the cashiers to study, and therefore the cashiers studied were not necessarily those with the highest production or the speediest motions, unless at the same time their motions were obviously good or particularly interesting.[5]

The films were carefully analyzed both as to the motions used by the individual cashiers and also as to the relation of the work-

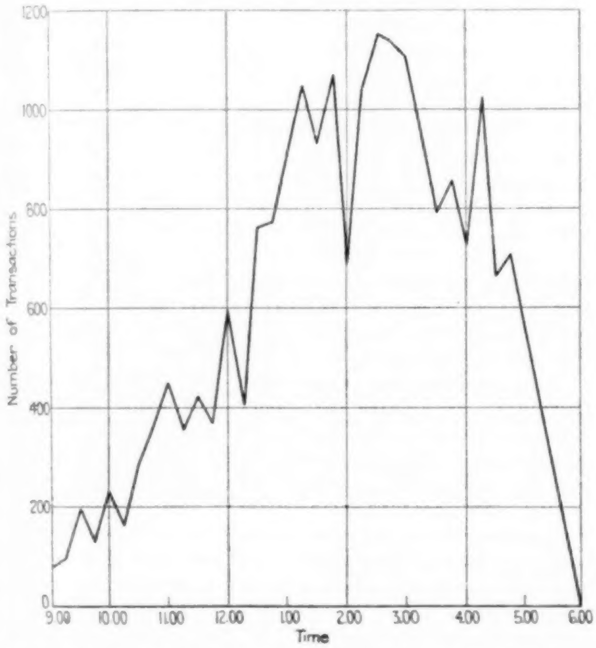


Fig. 4 Hourly Number of Transactions in "B" Tube Room—Saturday, March 26, 1927

place layout and the tools to the motions and variables of the cashiers. The cycles or complete transactions which showed differences in method, the use of fewer or more therbligs, the variables in the work, etc., were analyzed on simo charts. Twenty or more simo charts were made, one of which is shown in Fig. 3. Since different colors indicate the different therbligs, the different charts show clearly the variations in the therbligs used and also in the length of time spent on each therblig.

[4] [The process chart prepared by the authors and presented by them at the time the paper was read contained the complete data of the entire process. It is too large to be reproduced satisfactorily. Fig. 2 contains only that part of the chart which applies to the cashier's activities and only enough of these are shown to give an idea of how the chart is made and what it contains.—Editor.]

[5] [On the occasion of the presentation of this paper, the authors showed the motion pictures of the "present" and the "improved" methods. Some sections of these films are included on the process chart of Fig. 2 and show the clock from which the time elements were taken when the simo charts (Fig. 3) were made.—Editor.]

### Other Data Relating to Work

Other data relating to the cashiering work included information on the flow of business in the tube rooms. Figs. 4, 5, and 6 show the peaks in the tube-room business. Statistical data on the cost of operations of the tube rooms were also studied. Time studies were made of the cashiers to find the average time required per transaction, and, from the customer's point of view, studies were made on the selling floor of the time required to get change. These data were collected in order to have all data bearing upon the situation which were essential for complete analysis, as well as records of the "present" situation, so that

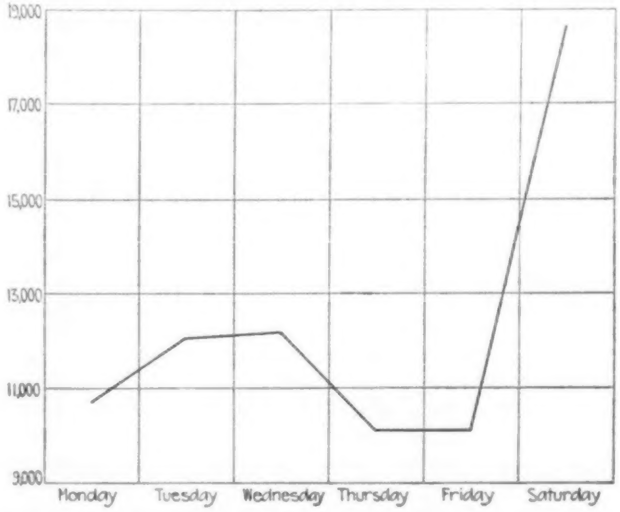


Fig. 5 Total Number of Transactions in "B" Tube Room—March 21 to 26, 1927

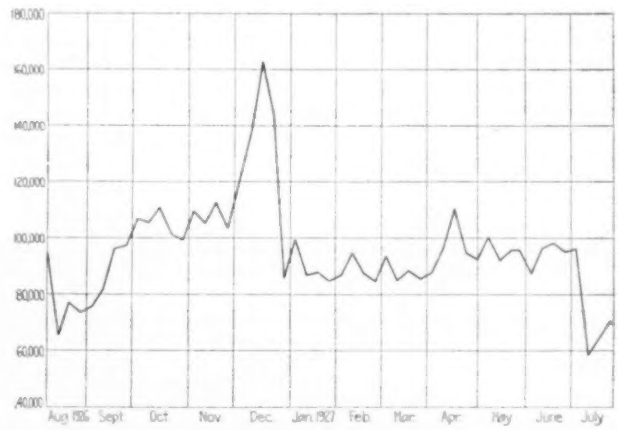


Fig. 6 Weekly Total Transactions Handled in Basement Tube Room—August 1, 1926, to July 31, 1927

comparisons could be made after changes had been determined upon and installed.

### Physical and Psychological Analysis

Each cashier was given a physical examination and various psychological intelligence and performance tests. A psychiatric analysis was also made, including personality traits, home conditions, schooling and training, age, etc., to discover the factors tending to affect the success of the cashier in this kind of work.

### Analysis of Present Practice and Improvements

All data on present conditions, methods, and workers were

then analyzed with the cooperation of the supervisors of the tube rooms and the cashiers themselves, all of whom considered the findings and the suggested change. Possible changes in the tube-room methods were considered in relation to the effect on the elements of the operation preceding and following.

For example, an analysis of the simo charts showed that from 27 to 34 per cent of the total time required to handle a transaction was required to write on and stamp the sales check. The cashier, as already explained, checked the extensions and additions of the sales check. After doing this she had to write the total amount of the sale on both copies of the sales check, the theory being that from a psychological point of view the cashier was forced to observe the amount of the sale carefully,


Fig. 7 Comparison of Old and New Cashier's Desks

and also that, in cases of dispute with the selling floor or the audit as to the amount of change given, the cashier's notation on the sales check would prove her interpretation of the sales check. The question then arose: Even so, was this writing necessary? And if so, was it necessary to write the amount on both copies of the sales check? After investigation, it was decided to retain the writing on one copy of the sales check only, but to eliminate it from the other copy.

Analyzing the methods of writing, it was found that one cashier held her pencil throughout the transaction, whereas all the others dropped theirs after the writing in one cycle and picked it up again when ready to write in the next cycle. The simo charts showed that the cashier who held her pencil used fewer therbligs at this point, and also that these therbligs which were eliminated helped her to perform this part of the transaction much more quickly than the other cashiers could. In fact, in some cases the pencil dropped back into the bill tills and then a "search" therblig was necessary in addition to a longer "transport empty" and "transport loaded," and to the "grasp" therblig. Experimenting with one cashier who had otherwise worked out excellent motions for herself, it was proved that after she had broken her habit of dropping the pencil and had established the new habit, her time for the operation was reduced, and that holding the pencil through the rest of the cycle did not prove a hindrance.

Two particularly bad features were obvious in the layout of the desk. First, the box in which the cashier put the copy of the sales check which she retained was at the upper left-hand corner of the desk. The cashier stamped both copies of the sales check with the stamp, located on the lower right-hand corner of the desk, and then carried her copy of the sales check to the box, diagonally across the desk, the longest distance. It was desirable to keep the stamp on the right-hand side for ease in stamping with the right hand, but the sales-check box was relocated directly under the stamp so that one copy of the sales check is dropped into the box as it is withdrawn from the stamp. Eliminating this long "transport loaded" and "transport empty" in the cycle reduced fatigue.

Another improvement in the desk was the relocation of the dispatch tube which had been behind the desk at the side next to the belt, so that the cashier had to turn partly around to reach it easily. Also, the mouth of the tube was very little larger than the carrier so that the carrier had to be positioned very carefully when dispatching it. The dispatch tube was relocated in the center of the desk but toward the side toward the belt, and a bell hopper was placed at the opening so that the cashier could throw the carrier in with practically no positioning. Fig. 7 shows the layout of the old and new desks.

The new desks were made 36 in. high with a comfortable foot rest at the bottom, and a work chair with a double saddle seat and adequate back support both for working and for resting was provided. With this equipment, the cashier easily alternates standing and sitting to reduce fatigue and the work place is equally convenient for both.

A locking device was also adopted so that the cashier no longer has to pack up her money and take it to the office every time she leaves her desk. This device has reduced the "get ready" time.

Improvements were also made in the surrounding conditions. The desk lights were removed, and greater general illumination was obtained by installing larger fixtures of the proper type at regular intervals, thus providing an even distribution of light with a minimum of shadows. An average uniform illumination of 18 foot-candles was provided. Noise was lessened by covering the drums and air tubes with felt padding and the walls with acousticon. Ventilation in one tube room was improved by installing screens, and the vibrations in the tube room directly over the engine room were reduced materially by supporting the lines from the floor of the engine room instead of from the ceiling under the tube room.

Rest pauses were also considered, and definite rest periods in the morning and afternoon were encouraged during busy periods. Separate rest rooms were established next to each tube room, so that cashiers could relax completely without traveling a long distance to and from the regular employees' rest room.

Other improvements were possible, but were not installed because of certain limiting factors.

## Setting Task and Incentives

Ordinarily, the next step in such a study as this would be to

set the task. This is determined by the times obtained from the micromotion study, augmented by continuous-production studies made over a whole day, or representative parts of the day, to get complete information on rest pauses and delays. The task would then be set on the basis of these times and the flow of work, and an incentive plan would be developed.

In this case, however, a standard of production and a bonus plan had been in operation for years. Since rate cutting is not consistent with the company's policy, it was decided not to change the task and the incentive plan, even though changed methods would make greater production possible with the same amount of effort.

### Selection and Training of Workers

The establishment of the best method of doing cashiering made it possible for the psychological and psychiatric department to develop a definite technique for employing new persons who would make successful cashiers. Using the definite and complete analysis of the job with the degree of success of the individual cashiers as criteria, the conference office of the employment department has been able to work up standards for age and schooling, and for physical, psychological, and psychiatric qualities.

Job specifications have been worked up for interviewers which give a brief but graphic description of the job and its functions, and which also include the personnel qualifications worked up by the conference office. For the applicant, there have been prepared descriptions of the job from the employee's point of view, the nature of the job, its relation to the rest of the store, the working conditions, the task-and-bonus plan, and the promotional opportunities.

The department of training has also found it much more satisfactory to use definite motions in training cashiers. The equipment of the tube room has been duplicated in the classroom—the same desks, chairs, etc., although the belt used here does not move. Real money has been substituted for theatrical money previously used in order to give definite training in handling coins and in mental arithmetic. From the first, the motions of the simo chart are used by the cashiers as the instruction card. Thus correct habits of motion are formed from the beginning.

### Results of Study

This study of cashiering has benefited the customers, the store, and the employees.

The result from the customer's point of view is that the service has been improved 26 per cent on the average. The present time required by the cashier is 17 per cent lower than the previous time of the best cashier, and 40 per cent lower than the poorest of a selected group of good cashiers.

From the point of view of the store, the study has resulted in a reduction in operating expense. Previous to the time of the study the average production of the cashiers was falling off, but since the better methods were determined the average production has increased. The table below compares average production in 1924, before these changes were made, with that in 1926.

| | 1924 | 1926 | Per cent increase |
|---|---|---|---|
| Full-time cashiers......... | 543 | 682 | 25.6 |
| Part-time cashiers......... | 362 | 434 | 19.9 |

The individual production of a cashier has increased. On the busiest day in 1924, the Saturday before Christmas, before the study, the best cashier had handled 2220 transactions. In 1925 the number had increased to 2738.

Another important fact which has made the tube-room operation less expensive since the study is that a shorter time is now required for the new cashiers to get up to standard production due to the improved selection and training methods.

To the cashier herself the new method has proved advantageous also. For example, higher bonuses have been earned: during the first December after the bonus was introduced, the total bonus earnings increased 88 per cent, over the December of the year before, and 44 per cent more cashiers earned a bonus, although the number of cashiers had not increased. The cashiers are now better adapted to their jobs. Moreover they are interested in the amount of skill they can develop and consequently find their jobs much more satisfying. And most important, much fatigue has been eliminated, so that the cashier is able to do more work without additional fatigue. This elimination of fatigue has resulted, as described above, from eliminating waste motions and by doing the necessary motions in the best way, and also by improving the surroundings and posture of the cashier.

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# An Application of Motion Study to Group Work in Industry MAN-50-17B

By JOS. A. PIACITELLI,[1] NEW YORK, N. Y.

THE SUBJECT of motion study has been so thoroughly covered in the paper[2] by Miss Lies and Miss Sealy that it is hardly necessary to discuss further its principles. However, some of the points may be emphasized and there may be added a discussion of the analysis of work in general, mentioning briefly some of the major differences in the various techniques and pointing out some of the limitations under which the analyst must work when making a study of an operation.

The methods of study commonly known today may be grouped into two classes. Time study and operation study will fall into one, and micromotion study and time and motion study into the other of these classes. For convenience these two classes will be referred to hereafter as time study and motion study. The chief differences in them are in the manner in which the observations are made. When employing the time-study technique the analyst must make all observations relative to methods and general layout of equipment and tools with the naked eye. Using this technique, time records are made by standardizing the method and then breaking it up into subdivisions suitable for stop-watch observation, and finally the time for each subdivision is observed and recorded. With the motion-study technique a simultaneous record of the method and time as well as the layout of equipment, machinery, and tools is made with a motion-picture film and a Gilbreth clock. Advance standardization of method is not necessary in this case, for standardization

[1] Assoc-Mem. A.S.M.E.

[2] See paper no. MAN-50-17.

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follows the establishment of the best method, which itself is the result of investigation. In the time-study technique the time element is considered the most important factor toward the solution, while with motion study the major contribution to the solution is expected from the analysis of the method. However, it must be remembered that, regardless of the technique employed, both the time and the method must be considered to obtain satisfactory results.

The characteristics of the work to be analyzed play an important part when determining the technique to be employed. There are jobs in which the percentage of handling time to the total cycle time is very small, and it is then most important to study closely the performance of the machinery employed. In operations consisting largely of handling work, and especially those highly repetitive, the motions made by the worker must be analyzed in order to establish the best method before any attempt at standardization is made.

The analyst using the stop watch must often work under limitations which make it impossible for him to get detailed and accurate data. A time study can be made with a stop watch only as long as the elements into which the job is divided are performed in sufficient time to permit the reading and recording of time data. But when short-cycle operations are studied and the elements on which time data are desired are performed in a few seconds, the task of making a usable record becomes rather difficult. Because of the error involved in the stop-watch readings it is usually difficult to time sub-operations lasting less than two seconds, and even more difficult to observe accurately and simultaneously the method employed during any one period timed. The motion-picture and Gilbreth-clock method not only makes the simultaneous observation practical, but reduces that part of the analyst's work to a comparatively simple procedure.

For example, for the purpose of studying a winding operation and establishing a more economical method of winding and handling rolls of felt, a motion-picture film was made. The crew consisted of a winder, a cutter, a helper, and a scale man, and it was possible to get data pertaining to methods and time of the four men in two scenes. A roll of saturated felt 74 in. wide was wound on the machine equipped with one winding mandrel and was cut off from the continuous sheet by the cutter. It was then transported with the mandrel still in its core to a tying table about six feet away by the winder, cutter, and helper. The mandrel was taken out of the roll by these men and transported back to its bearings on the machine. The winding of another roll was started by the three men, who simultaneously grasped the saturated felt sheet, passed it around the mandrel, and tucked its end between the sheet and the side of the mandrel. The expansion of the mandrel was performed by the winder and accomplished by turning an expanding nut on the end of the mandrel with a spanner wrench. As soon as this was done the machine was ready to wind the next roll. Starting and stopping of the machine were effected by the operation of a rheostat controlled by the winder, who was required to move to the side of the machine to do it. When the roll was wound to full length the winding was stopped by collapsing the mandrel after the power had been shut off but while it was still in motion. The roll was then cut off and removed from the machine and the cycle repeated.

When placed on the tying table the roll was tied with two pieces of muslin tape, to prevent unwinding, by the scale man, whose other duties consisted of tipping the roll off the tying table on to a scale, weighing and marking the weight on it, and again tipping it on to a roller conveyor which loaded it inside of a box car stopped alongside the door. As a matter of production and shipping record this man was also required to make note of the weight of each roll.

As a preliminary analysis, a process chart[3] was made of the simultaneous activities of these men, showing as accurately as it was possible to observe with the naked eye, what they did and how they did it. To those who were familiar with the operation many suggestions for improvement were obvious, but without time data of the elements of motion involved in the various sub-operations, it was not easy to rearrange the work to the best productive advantage nor to attempt to set a standard of performance in accordance with the possible new methods.

The film was taken and the time and method data for a selected cycle were put in form of visual records called "simo" charts. These charts made it possible to visualize the duration and sequence of each element of motion (therblig) in the complete cycle as performed by each hand of the operators, as well as any other useful activity of the body. The men interested, such as foremen, superintendents, and other engineers, were given the opportunity to analyze the work as represented on the charts and many useful suggestions toward lessening the fatigue and reducing cycle time were made by them.

Time does not permit the enumeration of all of the various changes made, but some of them should be noted. The reduction of the distance through which the roll and mandrel, weighing approximately 200 lb., had to be transported after they were taken off the machine, and the changing of the relative heights of the machine and tying and weighing table are a few of the changes which made the services of the helper unnecessary. In the old method three men were required to walk several steps with the load, while at present the roll and mandrel are moved the required distance by two men with a swing of the body and with less effort.

The comparatively long period of unavoidable delay during the winding process in the operating cycle of the three men was reduced by rearranging their work so that with the use of two mandrels they could remove the mandrel from the last roll wound, transport it to the machine, and partially expand it while the winding of the next roll was in process. The rearrangement of the cycle of this new sequence was greatly facilitated by the availability of the method and time data on the simo charts. The new method was finally established and shown on a new-method simo chart, consisting of a synthesis of the past performances recorded, together with data from other sources, such as that estimated for motions for which time data were not available, or that taken of similar elements modified to suit new conditions.

The work of the scale man has been very much simplified and fatigue greatly reduced by arranging the delivery of rolls directly on to a roller conveyor mounted on the scale, thus ridding him of the heavy work. In fact the few operations now performed by him, such as adding one muslin tape around the roll instead of two, marking the weight on the roll and recording it on an adding machine instead of a production record, can be taken over by the winder and cutter without any appreciable increase of fatigue or loss of time. However, in view of the fact that these two men will have little or no time to relax and overcome the effects of fatigue caused by their work, it was considered desirable to relieve them of as much work as was possible and to offer an additional opportunity to rest by maintaining the scale man and making provision for the rotation of functions among the three. A standard of performance was set allowing them 50 per cent over the synthesized minimum time, for delays and fatigue.

In brief, the solution may be summarized as follows: The present crew of three men is producing 40 per cent more than the former crew of four. The work is now less fatiguing and the earnings of the men have been increased on an average of 8 per cent, while the average reduction in labor cost is 42 per cent.

[3] For a description and example of process charts and simo charts see paper no. MAN-50-17.

MAN-50-18

# The Work Required to Operate Several Makes of Typewriters

By F. H. Norton,[1] Cambridge, Mass.

*This paper reports a series of carefully conducted tests made on five standard typewriters, manufactured by different companies and bought at retail stores, to determine the amount of work required for their operation.*

*To eliminate the human element and to make it possible to measure the work involved, the typewriters were operated pneumatically by a specially designed apparatus which also recorded on a photographic film a curve whose integrated area was proportional to the work. After mechanical operation had been adjusted so that it simulated satisfactorily manual operation, and after a careful calibration of the instruments and apparatus, tests were conducted on the operation of the following parts: the type keys, space bar, capital shift, line space, and carriage return. Tables of results show that a given typewriter may be superior to others, from the point of view of work required for operation, for one of these operations, and inferior to some other for another operation.*

*In order to interpret these results in combination, all of these five operations being necessary in varying degree in ordinary operation, 25 typical business letters were analyzed to determine the average number of times each operation was performed. It was then possible to determine the total work to type the average letter on each of the typewriters, and a table of these results is given.*

*In a summary of the results, it is pointed out that certain elements which are independent of the actual work of operating the typewriter but which seriously affect fatigue are not covered by the investigation. Recommendations are made as to adjustment and servicing of typewriters.*

The purpose of this investigation was the careful measurement of the amount of work required to operate various makes of typewriters. More specifically it was desired to find the work expended in the normal operation of the type keys, space bar, capital shift, line space, and carriage return for several machines of each make; to find the average number of times each of these operations occurred in a representative business letter; and from these figures to compute the amount of work required to type the average letter on each make of machine.

## Selection of the Typewriters

The typewriters used in this investigation were of five standard American makes. They were purchased with cash and without previous notice from their respective agencies in several different cities, and were carefully transported by automobile to Cambridge. The agents had no way of knowing that these machines were being purchased for the purpose of tests.

All of the machines were stated by the venders to be new machines, properly adjusted. No adjustments or alterations of any kind were made on the machines after purchase. The substitution of the special uniform platens for the regular platens was only made after all other measurements on type keys, space bar, capital shift, line space, and carriage return had been made. One make of machine regularly has supplied interchangeable platens of varying hardness. In this case the platen was selected which had a hardness nearest the mean of those supplied for the other makes. Throughout this report the makes of typewriters will be known as A, B, C, D, and E.

[1] Rogers Laboratory of Physics, Massachusetts Institute of Technology.

## Work Required by Type Keys

The precise determination of the work expended in operating a key is a rather difficult problem because the motion is rapid and the light moving parts must have no appreciable mass added to them. There seemed to be no possibility of constructing a sufficiently light recording pressure dynamometer for attachment to the key. The only possible method appeared to be rather complicated but fundamentally sound. This consisted of measuring the motion of the key when a typist operated it in the usual manner; and then constructing a mechanism which would reproduce this motion and at the same time record the pressure exerted throughout the stroke. As the movement of the key is the same in both cases, the work performed by the typist in pressing the key must be equivalent to the mean effective pressure

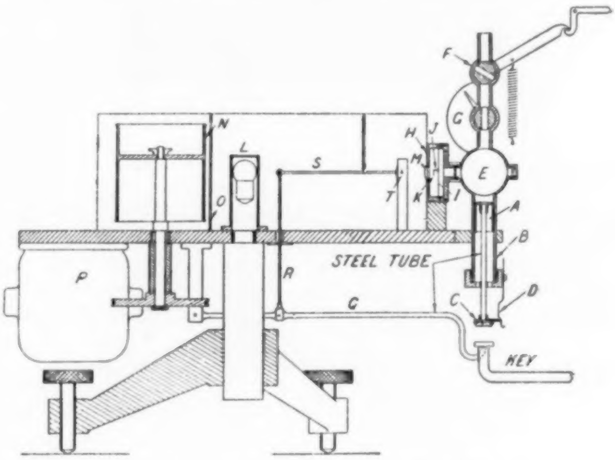



Fig. 1 Apparatus for Operating Type Keys

measured during the similar mechanical stroke, multiplied by the length of the stroke.

## Description of the Apparatus

The apparatus constructed for operating the key is shown in Fig. 1. The piston $A$ sliding in the cylinder $B$ operates through a piston rod, the felt covered disk $C$ which depresses the typewriter key. This disk can be initially held at any fixed height above the key by the stop $D$ which is so delicately adjusted as to offer practically no resistance to the piston movement. The piston was carefully lapped into the cylinder and an oil seal was provided by several narrow grooves cut around the piston. All the moving parts were kept very light so that their mass would be a small fraction of the mass of the key and its attached mechanism.

The piston is operated by admitting compressed air into the reservoir $E$ above the cylinder. In order that air should be introduced into the reservoir suddenly and in exactly the same way under like conditions, the spring-operated valve $F$ is used. This stopcock is held shut with a trigger and opened suddenly by a strong spring. In addition there is a graduated throttle valve $G$ to vary the rate at which air is introduced.

Connected directly to the reservoir by a short and relatively large passage (to eliminate any distortion of the pressure wave) is the high-frequency manometer *H*. This instrument is similar to the manometers used for pressure-distribution work on airplanes and airships. It has a natural frequency of about 300 vibrations per second, a constant calibration, a small temperature coefficient, and is not affected by vibration. The manometer consists of the diaphragm *I* with the stylus *J* attached to the center. The hardened tip of the stylus rests against the back of the stainless-steel mirror *K* which is mounted on pivots and held against the stylus by a watch hairspring. Therefore a slight movement of the diaphragm gives a considerable rotation to the mirror. Adjustments are provided for readily changing the zero setting or the sensitivity.

Light from the lamp bulb *L* passes through the lens *M* on to the mirror *K* and is reflected back through the same lens and focused on the film *N*. A slit *O* gives a point image on the film. The film, which is wound on a drum, is moved at a constant angular velocity by the motor *P* through suitable reduction gearing.

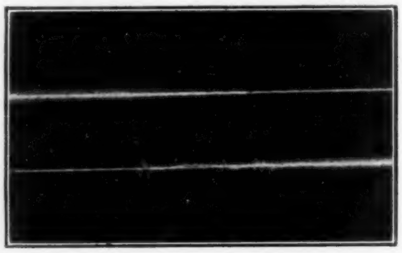


Fig. 2 Pressure Curves

This instrument makes records of the size shown in Fig. 2. The range of pressure as adjusted for this work is about 50 cm. of mercury. The recorded trace is so sharp that the record can be enlarged and read with much greater precision than is required here.

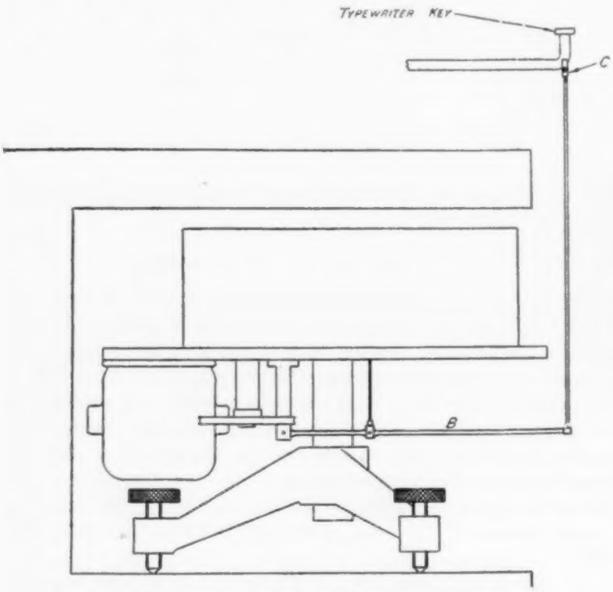



Fig. 3 Apparatus for Measuring Key Deflection

The movement of the key is recorded by a mechanism also shown in Fig. 1. The lever *Q* rests underneath the key and is pivoted at the back end. The link *R* connects it to a second lever *S* pivoted at *T*. On this pivot and behind a lens is a small mirror which reflects light from the lamp *L* on to the film. This allows the simultaneous recording of pressure and deflection.

When it is desired to record the key motion under manual operation, the set-up in Fig. 3 is used. The instrument previously described is placed upon a solid support under and at one side of the typewriter. A light strut *A* connects the lever *B* with the key through the fitting *C*. A record can be taken of the motion of any key, and the operator need not know which key is connected.

The air pressure supplied to the instrument is obtained from a tank of about 6 cu. ft. capacity which may be pumped up with a tire pump. The tank pressure is measured by a mercury manometer in the usual way. The system was tight enough to hold a substantially constant pressure for several days.

Fig. 4 Assembly for Obtaining Operator's Curve

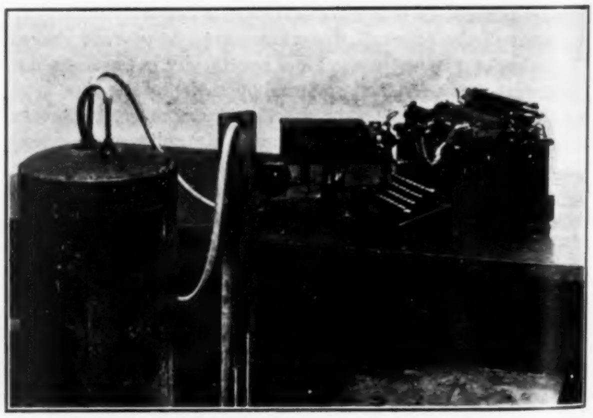


Fig. 5 Assembly for Duplication of Operator's Curve

## Calibration of Apparatus

The recording manometer on the instrument was calibrated by connecting it directly to the tank and taking a number of records with several known and constant tank pressures. The film records were measured and the distance of each recorded pressure line above the zero was plotted against the tank pressures.

It should be mentioned here that all of the films were measured by placing them in a projection lantern and tracing them off to a

large but constant scale on a sheet of paper. This method was rapid and saved eye strain, which was important when it is considered that more than 2000 records were taken in developing the apparatus.

The record of the key deflection was standardized by depressing the key with a micrometer screw and taking records at frequent intervals. The resultant curve of key deflection plotted against the motion of the spot of light across the film was a straight line. This gives a constant factor by which to multiply the distance on the film in order to get the key travel. This factor was 1.24 for the short lever of Fig. 1, and 1.20 for the long lever of Fig. 3.

Figs. 4, 5, and 6 show general views of the apparatus and give a good idea of the construction and method of operation.

Fig. 6 Assembly for Obtaining Impression Tests

### Key Motion With Manual Operation

A large number of records were made to show the key motion. These records brought out the following facts:

(a) A given operator does not exactly duplicate the record on successive trials.

(b) There is no great difference between records made by the several typists.

A number of operator's type-key-displacement records are shown in Fig. 7 to illustrate the points. From many data of this kind it was thought permissible to use the same skilled typist on all makes of machines, as this procedure in the end would give more strictly comparable results.

### Key Motion With Mechanical Operation

The next problem was to so adjust the pressure cylinder as to reproduce the preceding key motions. The following adjustments could be made:

(a) Air pressure
(b) Throttle-valve position
(c) Initial height of the pad above the key
(d) Softness of the pad
(e) Lower limit of piston travel
(f) Mass of the moving parts.

It is believed unnecessary to go into the details of the adjustments made. After some experimenting practically any hand operator's curve could be reproduced. An example is shown in Fig. 8. It was shown later that a considerable change in the

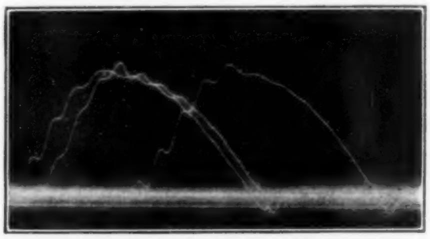


Fig. 7a

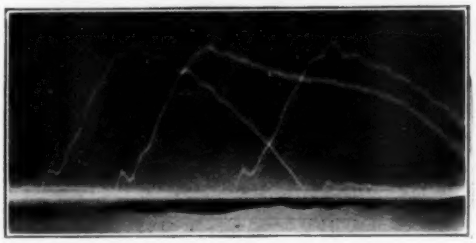


Fig. 7b

Fig. 7c

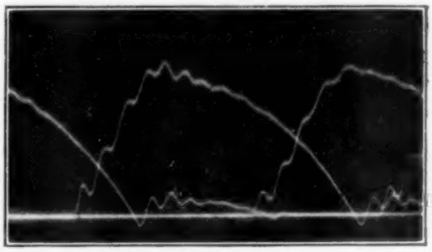


Fig. 7d

Figs. 7a and 7b Two Operators on the Same Machine and Same Key

Figs. 7c and 7d Single Operator on Hard and Easy Action

shape of the curve for a given tank pressure will have little effect on the type impression on the paper.

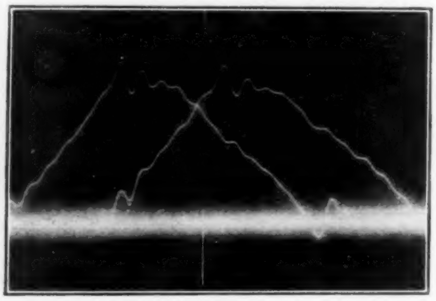
Now that it is certain that the manual motion of the key can be reproduced mechanically, the pressure curves taken simultaneously with the displacement curves are of chief importance.

In Fig. 9 are shown simultaneous pressure and displacement curves redrawn from the original of a typical record, to give a larger scale. It will be noted that the pressure rises very rap-

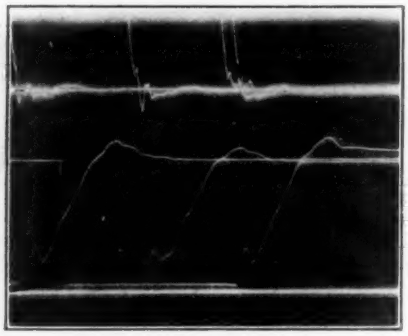
idly—in 0.0005 sec.—and, except for a slight surging on reaching the maximum, remains constant for the remainder of the stroke.

The work accomplished during the stroke is evidently equal to the mean effective pressure during the stroke multiplied by the length of the stroke and the piston area. This is the same condition occurring in engines and needs no further explanation. We have only to define the stroke and mean effective pressure.

Referring to Fig. 9, the stroke is given as the distance $L$, and the time by $t$, and the mean effective pressure by the shaded area divided by $t$. As the pressure on the piston is equal to the tank pressure for much of the stroke, it might be expected, that there would be a constant relation between the tank pressure and the mean effective pressure. Could this relation be established, a great deal of time would be saved as a pressure record would not have to be taken and measured for each stroke.



Mechanical



Manual

Fig. 8 Reproduction of Operator's Curves

(The difference in height of curves is due to difference in length of magnification arm of the instrument. The oscillation shown in all curves is due to the elasticity of the key levers.)

A number of records were made on the easiest- and hardest-working machines at different pressures with the instrument assembled for operating keys, space bar, capital shift, line space, and carriage return. The mean effective pressure for each case was computed from the planimetered area under the pressure curve. The mean effective pressure thus found is plotted against the corresponding tank pressure in Fig. 10. As expected, the points fall closely on a straight line up to a pressure of 35 centimeters of mercury. Above this the points depart sharply from the line which is undoubtedly caused by the forcing of the oil out of the piston grooves at this pressure. This is confirmed by the commencement of hissing when the pressure reaches this value. The use of a heavier oil would raise this critical pressure, but as it is above the range used in these tests no change was deemed necessary.

The slope of the curve in Fig. 10 gives the factor by which to multiply the tank pressure in order to obtain the mean effective pressure. The work is given by

$$W = APKdgL$$

where

$W$ = work in ergs
$A$ = piston area, here = 1.292 sq. cm.
$P$ = tank pressure in cm. of mercury
$K$ = constant to convert tank pressure to mean effective pressure = 0.97
$d$ = density of mercury = 13.6 grams per cc.
$g$ = acceleration of gravity = 980 cm. per sec.
$L$ = length of the stroke in cm.

### Comparison of the Impressions

Now that it is possible to obtain the work for a given key stroke, it is necessary to be able to duplicate the effectiveness of the stroke on all machines. This was done by using in all tests pieces of ribbon from a lightly inked ribbon 144 yards long obtained from a well-known manufacturer. Sheets of paper were used from the same package. Then by making typewritten records on each machine at a number of tank pressures, the pressure giving the nearest approach to a standard could be selected. In all such impression tests two carbon copies were made.

The selection of the tank pressures giving equal impressions is the least precise part of this investigation. By carefully examining the impressions of a number of letters in the standard and on the test sheet with a magnifying glass, two independent observers are almost always able to check each other within a pressure of one centimeter of mercury. It does not seem possible to obtain a greater precision than this because of irregularities in type, paper, and ribbon, and because of the uncertainty of matching impressions by the eye. However, this gives a precision of from 3 to 5 per cent for a single machine.

It was believed that the hardness of the platens might vary between the different makes of machines and partially account for the differences in work required to make a standard impression. A hard platen would undoubtedly require less work to produce a given impression than a soft platen. After all other tests had been completed on the machines, special uniform rolls, made up by turning about 2 mm. from the diameter of the regular platen and forcing on a brass tube of the original diameter, were substituted for the regular platens. The pressure was determined that would give a standard impression. In all cases the pressures were lower, but the comparison was made difficult because of the irregularity of the impressions made on the special uniform platen.

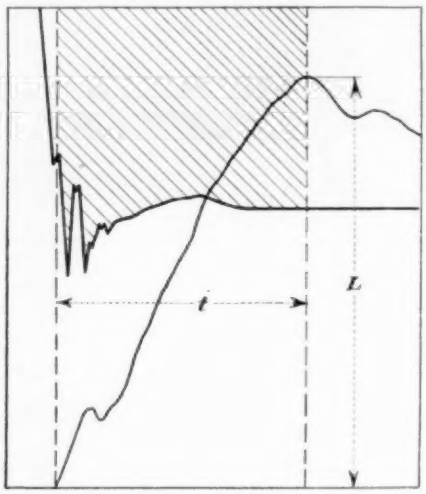



Fig. 9 Enlarged Pressure-Displacement Record

### Method of Making Tests on Type Keys

Each typewriter was tested by placing the air cylinder directly over the key and raising the piston to the proper height. Two carbons and three sheets of paper were placed in the machine. The tank was pumped up to the desired pressure, the trigger released, and the impression made. This procedure was repeated for all the letters across the second row from the bottom, at the same tank pressure. The tank pressure was then raised 1 cm. and another row of impressions made. These impressions were then compared with the standard in the manner previously described.

### Results on Type Keys

The results obtained for the type keys of the twenty-five machines tested are listed in Table 1.

On examining these results it will be noticed that there is a considerable variation in work between different makes of typewriters and a smaller variation between machines of the same make. While it is not within the scope of this report to analyze the motion of the typewriter mechanism, it is believed that most of this variation is due to the resistance offered by the carriage escapement. In fact, a small adjustment of the escapement spring will greatly alter the work required to operate the key.

In general the special uniform platen required about 0.7 of the work needed to give the same impression on the standard rubber platen.

The order of merit of the various machines in regard to type-key work is E, A, C, D, and B.

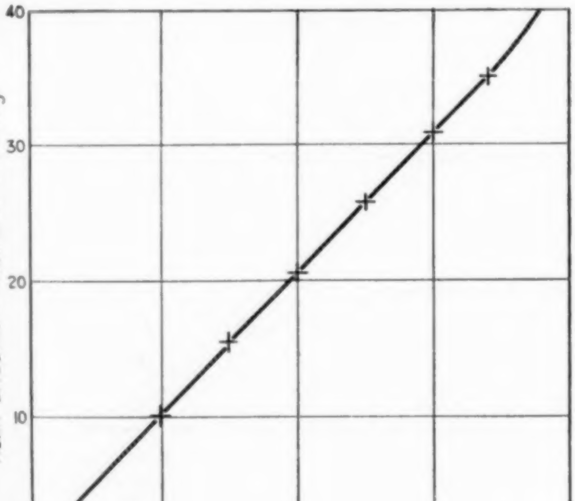



Fig. 10 Relation Between Mean Effective Pressure and Tank Pressure

It was also noticed that there is some variation in length of stroke. It should be kept in mind that the relative work required to operate the keys may not be a measure of the fatigue suffered by a typist. That is, of two machines requiring the same work, the one with a long, easy stroke might be less fatiguing than the one with a short stroke.

### Work Required by Space Bar

The method of obtaining the work necessary to operate the space bar was somewhat different from that used for the type keys because no impressions are made. The method finally used consisted in obtaining typical displacement curves for the space key on each make of typewriter when operated by a skilled typist. Displacement curves were then taken when the key was operated pneumatically, at several tank pressures. A curve was then plotted of tank pressure against the time taken for the stroke as measured from the enlarged curve in the way previously described. The pressure on this curve corresponding to the time taken for the stroke by the typist was the desired value. Curves of this kind are shown in Fig. 11.

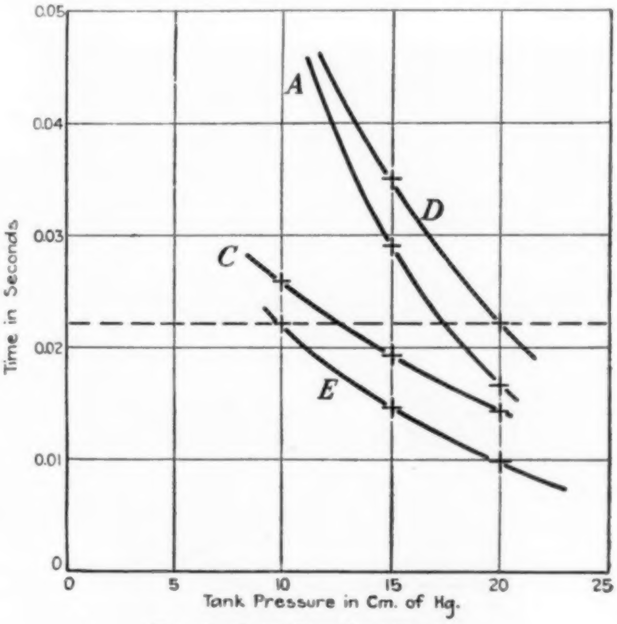



Fig. 11 Space-Bar Time Curves

The apparatus was the same as used for the type keys, but the operating pressure was considerably less.

### Space-Bar Motion

In Figs. 12*a* and 12*b* are shown several pressure-displacement curves for the space bar. They differ from the type-key records in having a shorter stroke and a definite stop. The average time required for the stroke was 0.0223 sec.

TABLE 1 WORK PER STROKE[1]

| Make | Type keys: Rubber platen | Type keys: Special uniform platen | Space bar | Capital shift | Line space | Carriage return |
|---|---|---|---|---|---|---|
| | 55 | 40 | 37 | 147 | 410 | 1100 |
| | 43 | 31 | 47 | 162 | 550 | 1590 |
| A | 45 | 38 | 52 | 124 | 620 | 1310 |
| | 45 | 35 | 51 | 141 | 600 | 1340 |
| | 50 | 38 | 34 | 131 | 590 | 1370 |
| Average | 47.6 | 36.4 | 44.2 | 141.0 | 554 | 1280 |
| | 102 | 60 | 26 | 212 | 400 | 1430 |
| | 69 | 54 | 21 | 131 | 310 | 1530 |
| B | 57 | 42 | 26 | 137 | 330 | 1320 |
| | 76 | 45 | 21 | 122 | 370 | 1600 |
| | 76 | 54 | 24 | 164 | 440 | 1210 |
| Average | 76.0 | 51.0 | 23.6 | 153.0 | 370 | 1420 |
| | 76 | 48 | 23 | 104 | 460 | 990 |
| | 57 | 42 | 23 | 95 | 300 | 1430 |
| C | 57 | 48 | 30 | 78 | 480 | 1660 |
| | 54 | 40 | 42 | 106 | 550 | 1230 |
| | 57 | 45 | 30 | 106 | 550 | 1400 |
| Average | 60.2 | 44.6 | 29.4 | 98.0 | 468 | 1340 |
| | 76 | 54 | 37 | 147 | 270 | 1320 |
| | 59 | 42 | 26 | 107 | 190 | 1370 |
| D | 62 | 39 | 39 | 95 | 290 | 1580 |
| | 66 | 45 | 28 | 95 | 390 | 1540 |
| | 57 | 45 | 37 | 89 | 280 | 1620 |
| Average | 63.2 | 44.0 | 32.4 | 107.0 | 286 | 1490 |
| | 40 | 36 | 13 | 94 | 360 | 1020 |
| | 45 | 36 | 21 | 94 | 300 | 1100 |
| E | 40 | 32 | 22 | 106 | 520 | 1270 |
| | 48 | 39 | 25 | 106 | 540 | 1090 |
| | 38 | 31 | 23 | 135 | 480 | 1260 |
| Average | 42.2 | 34.8 | 20.8 | 107 | 440 | 1150 |

[1] The work is expressed in ergs divided by 10,000.

As the same piston was used for the space bar and type keys, the same factor for converting the tank pressure to mean effective pressure was required. The work, as before, is calculated from the same equation as the type-key work.

### Results on the Space Bar

The results for the machines tested are given in Table 1.

The values of the work required by the space bars are about one-half of those for the type keys, due to the shorter stroke and lower resistance. It appears that there is little relation between the type-key and the space-bar work. For example, the machine which has the next to the lowest value for the type-key work had distinctly the greatest value for the space-bar work.

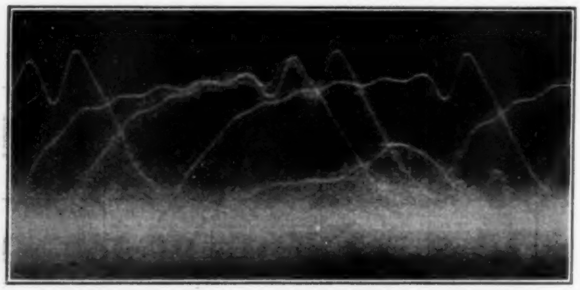


Fig. 12a Operator's Records of Space Bar

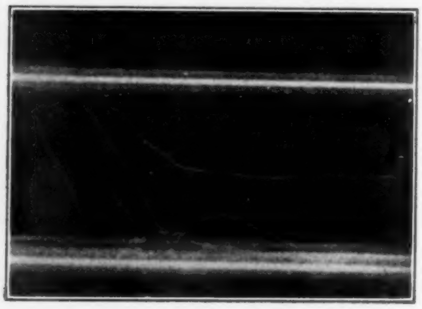


Fig. 12b Pressure-Operated Records of Space Bar

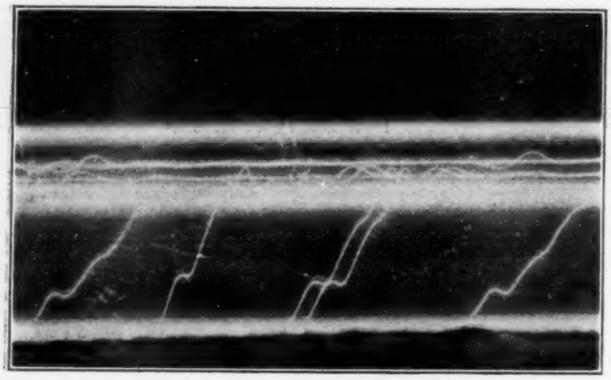


Fig. 13 Shift-Key Pressure-Displacement Records

The makes of machines may be rated in order of merit in regard to the work required by the space bar as follows: E, B, C, D, and A.

### Work Required to Operate Capital Shift

The force required to operate the capital shift was so much greater than that for the other keys that a pressure of 50 to 60 cm. of mercury was needed. A pressure of this magnitude blows the oil from the piston rings and causes a bad leak. For this reason a new cylinder and piston were constructed of twice the diameter of the previous one, but in all other respects the same.

The method of obtaining the work was identical with that used for the space bar. In Fig. 13 are shown a number of pressure-displacement records for the shift key. The time of stroke is comparatively long, averaging 0.067 sec. The lengthened time is due to the large mass that must be moved.

The work required to operate the shift key on the machine is given in Table 1. The work is computed from the same equation as for the space bar, in this case the area $A$ being 5.08 sq. cm. instead of 1.292 sq. cm. The constant $K$ is 0.97 as before, measurements having been made of planimetered pressure curves to determine this value.

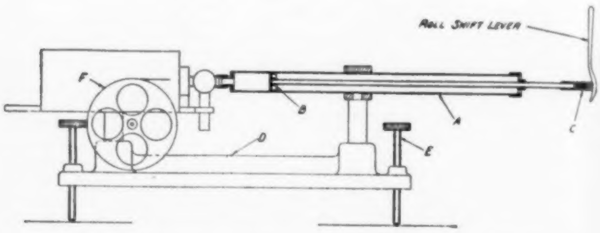



Fig. 14 Apparatus for Operation of Roll and Carriage

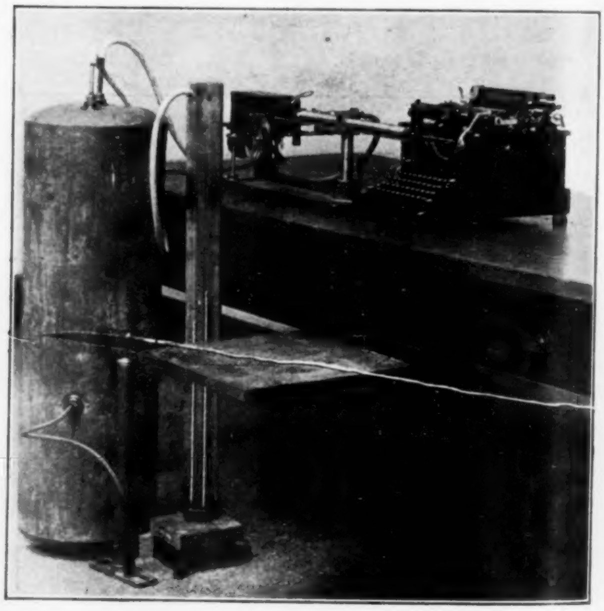


Fig. 15 Apparatus for Moving Line Space

The work required to operate the shift key is about three times as great as for the type key. There is about the same variation between machines as for the type keys. The order of merit is: C, E, and D the same, A, B.

### Work Required to Operate Line Space

The method of obtaining the work required to operate the roll was the same as used for the capital shift; the operator's time was reproduced mechanically and the work computed from the pressure and the stroke. The work was obtained for moving the roll a single space as this is used probably as much as a double space in letters, and serves as a simple comparison between machines.

The apparatus used for this test is shown in Figs. 14 and 15. The same air chamber, valves, and recording manometer are used as before, but a new cylinder *A* is provided in a horizontal position. The piston *B* forces the rod and finger *C* against the line-space handle. A heavy base *D* is provided with leveling screws *E* for vertical adjustment.

The motion of the line-space handle is recorded by attaching a piece of silk cord to it and running it around the large pulley *F*. This pulley is very light and is mounted on a small shaft. A fine cord wound on this shaft connects to the arm of the displacement mirror previously described.

Records were first taken on each make of machine when the line space was operated by a typist. From these records the time taken to complete the operation was measured as 0.0363 sec. The roll was then shifted mechanically at several pressures and a curve plotted as previously described for the space bar. In this way the pressure needed to reproduce the motion of the typist was obtained. A number of deflection curves are shown in Fig. 16, the motion being taken in the center of the hook on the line-space lever. The length of stroke was measured as the length of piston travel while the finger was in contact with the key. This was measured at the time of taking the records.

Table 1 gives the results of tests on the roll. The work was computed as before, the piston area being 5.08 sq. cm. and the constant *K* being again experimentally determined as 0.97.

The work necessary to operate the roll one space is considerably greater than that required to operate the keys. The order of merit of the makes of machines is as follows: D, B, E, C, and A.

### Work Required to Operate Carriage Return

The apparatus and method for determining the work to operate the carriage return were the same as for the line space. The stops were set to allow a motion of 66 spaces to represent a fairly long line. As the pressure was constant during the stroke it was assumed that the work required for shorter lines would be less in proportion to the length.

The records of Fig. 17 show some curves of carriage motion, and bring out clearly the relatively low velocity attained. The average operator's time for the carriage return of 66 spaces was 0.332 sec.

The data obtained and the computed values are summarized in Table 1. The calculations are based upon a 33-space return in accordance with values to be summarized in a later table.

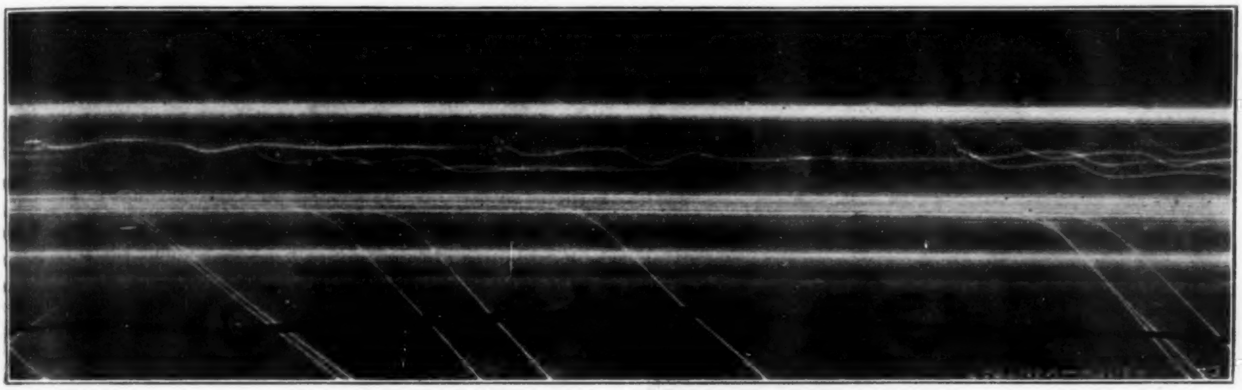


Fig. 16 Line-Space Deflection at Various Pressures
(Upper curves, pressure; lower curves, displacement.)

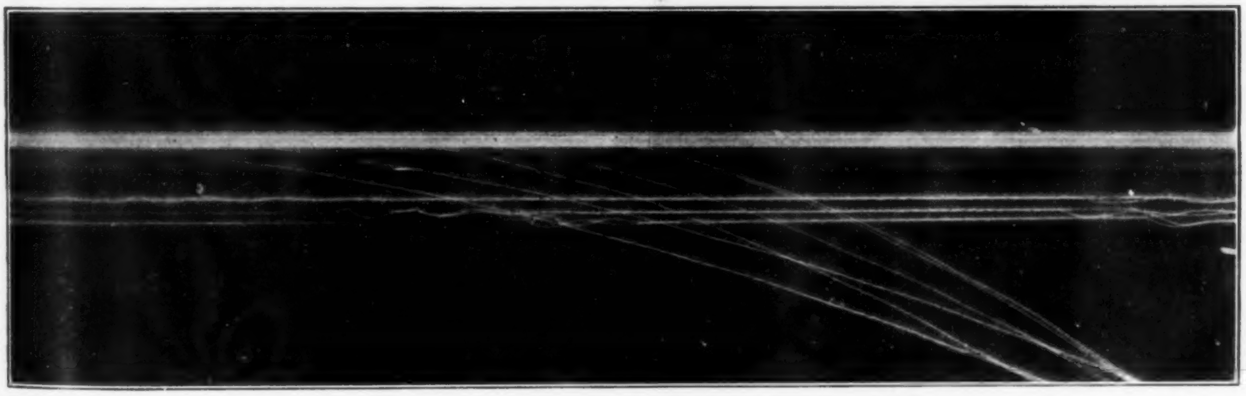


Fig. 17 Carriage-Shift Curves

The carriage requires a large amount of work for returning. However, a comparatively great uniformity of the values is shown, not only between machines of the same make but between different makes. This is probably due to the fact that the carriage spring tension can be accurately and permanently adjusted. The order of merit for carriage-return work is E, A, C, B, D.

### Analysis of Business Letters

Twenty-five letters were selected at random from a set of correspondence files with only the following limitations: (*a*) no two from the same correspondent, and (*b*) pica type.

These letters were analyzed by carefully counting the following characteristics of each letter, including the address on the envelope:

(a) The number of characters appearing, average 708

(b) The number of single spaces, counting no spaces longer than two consecutive single spaces, average 119

(c) The number of times the capital shift had been operated, average 38

(d) The number of single-spaced lines between the beginning and end of the letter, counting all untyped lines (for the roll motion), average 38

(e) The number of lines actually typed (for the carriage motion), average 25.

It is not claimed that the averages obtained here would be duplicated by selecting a second lot of 25 letters, but it is believed that the deviation would be so small that the additional labor involved in obtaining a more representative average would not be justified. At any rate the same figures are used for all makes of machines so that their comparison is not affected.

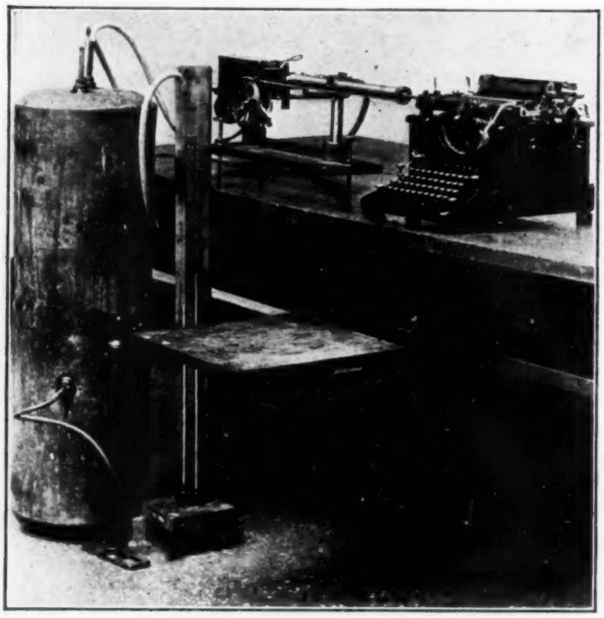


Fig. 18 Apparatus for Moving Carriage

## Total Work Required to Write the Average Letter

The sum of the amounts of work required for every operation on the typewriter multiplied by the number of times that the operation occurs in the average letter will give the total work used in writing the letter. These values are given in Table 2.

### Precision of Results

We may consider the precision of the work measurements both for the individual components and for the total. If we were interested only in the total work required to write the average letter, no component need be determined any closer than the one of least precision. An examination of the work shows that a majority of the total is made up of the type-key work and the carriage-return work. Therefore the remaining components need be determined with relatively less precision as their effect on the total is small.

However, as it was believed that considerable information could be obtained by a direct comparison of the separate components, they were all obtained with about the same percentage of accuracy.

The work of the type keys was obtained with a precision of ± 5 per cent; that is, different tests under the same conditions could be checked within this amount. The other components had a precision of from ± 3 to 5 per cent. The total work for the average letter should have a probable error somewhat less than that for each component, or around ± 3 per cent.

TABLE 2 TOTAL WORK TO TYPE AVERAGE LETTER[1]

| Make | Type keys: Rubber platen | Type keys: Special uniform platen | Space bar | Shift key | Line space | Carriage return | Total work: Rubber platen | Total work: Special uniform platen |
|---|---|---|---|---|---|---|---|---|
| | 39 | 28 | 4 | 6 | 16 | 26 | 91 | 80 |
| | 30 | 22 | 6 | 6 | 21 | 38 | 101 | 93 |
| A | 32 | 27 | 6 | 5 | 24 | 32 | 99 | 94 |
| | 32 | 25 | 6 | 5 | 23 | 32 | 98 | 91 |
| | 35 | 27 | 4 | 5 | 22 | 33 | 99 | 91 |
| Average | 33.6 | 26.2 | 5.2 | 5.4 | 21.2 | 32.2 | 98 | 90 |
| | 72 | 42 | 3 | 8 | 15 | 34 | 132 | 102 |
| | 49 | 38 | 3 | 5 | 12 | 37 | 106 | 95 |
| B | 40 | 30 | 3 | 5 | 13 | 32 | 93 | 83 |
| | 54 | 32 | 3 | 5 | 14 | 38 | 114 | 92 |
| | 54 | 38 | 3 | 6 | 17 | 29 | 109 | 93 |
| Average | 53.8 | 36.0 | 3.0 | 5.8 | 14.1 | 34.0 | 111 | 93 |
| | 54 | 34 | 3 | 4 | 18 | 24 | 103 | 83 |
| | 40 | 30 | 3 | 4 | 11 | 34 | 92 | 81 |
| C | 40 | 34 | 4 | 3 | 18 | 40 | 105 | 99 |
| | 38 | 28 | 5 | 4 | 21 | 30 | 98 | 88 |
| | 40 | 32 | 4 | 4 | 21 | 34 | 103 | 95 |
| Average | 42.4 | 31.6 | 3.8 | 3.8 | 17.8 | 32.4 | 100 | 89 |
| | 54 | 38 | 4 | 6 | 10 | 32 | 106 | 90 |
| | 42 | 30 | 3 | 4 | 7 | 33 | 89 | 77 |
| D | 44 | 28 | 4 | 4 | 11 | 38 | 101 | 85 |
| | 46 | 32 | 3 | 4 | 15 | 37 | 105 | 91 |
| | 40 | 32 | 4 | 3 | 11 | 39 | 97 | 89 |
| Average | 45.2 | 32.0 | 3.6 | 4.2 | 10.8 | 35.8 | 100 | 87 |
| | 28 | 25 | 2 | 4 | 14 | 24 | 72 | 69 |
| | 32 | 25 | 3 | 4 | 11 | 26 | 76 | 69 |
| E | 28 | 23 | 3 | 4 | 20 | 30 | 85 | 80 |
| | 34 | 28 | 3 | 4 | 21 | 26 | 88 | 82 |
| | 27 | 21 | 3 | 5 | 18 | 30 | 83 | 77 |
| Average | 29.8 | 24.5 | 2.8 | 4.8 | 16.8 | 27.2 | 81 | 76 |

[1] All figures in this table should be multiplied by 10,000,000 to give work in ergs.

### Conclusions and Recommendations

These tests bring out strikingly the fact that a comparative test made on a single machine of each make would be entirely misleading. Undoubtedly an average of, say, ten machines would give a more representative set of values, but it would be rather unlikely that the relative order of the makes would be changed except possibly in the case of machines C and D.

The marked variability of the work required for different machines of the same make is rather surprising, and brings out clearly the lack of uniformity of adjustment. Again, some makes of machine will require the least amount of work for one of the operations, but no single make holds the advantage in all. If we select the least value for the work of each separate operation in Table 2 and add them, we obtain the figure 64, which is about 0.6 of the average value found for all machines. This brings out the practicability of greatly reducing the work required to write a letter.

The tests indicate clearly that every typewriter of each make should have a standardized factory adjustment. This adjustment should be carefully determined from a thorough study of the machine; and it should give the best compromise between ease of operation, speed, and durability. The typist should be given a machine adjusted for the most efficient operation, and this adjustment should not be changed because of individual inclinations. This would have the distinct advantage of operating under conditions of maximum efficiency and would allow a change from one machine to another without discomfort or extensive servicing. The local adjusters should be permitted only to check the factory adjustment, but not to alter it. In this way all machines would have the same operating characteristics—the best. This program could not perhaps be carried through abruptly, but should start in the schools and in a few years cover all machines used.

There is another aspect of this problem that should not be forgotten. This is the well-recognized physiological fact that work accomplished does not measure effort or fatigue, as a few examples will show. As indicated in Table 2, the work expended

on the keys is about equal to the work expended in returning the carriage, for the average letter; yet nearly every one will admit that it is more tiring to strike the keys 700 times than to move carriage 24 times. Again, the total work needed to type a letter is the same as the amount that would be required for the average person to step up one step on the stairs; and it is needless to say that the typing of 20 letters takes more physical effort than climbing one flight of stairs. This discrepancy between work accomplished and fatigue is mainly due to two things: the muscles not only expend their energy in performing external work, but also perform work in moving the parts of the body, such as the hands and fingers; and the more powerful muscles of the body perform a given amount of work with less fatigue than the weaker ones. This all leads to the conclusion that the work required to operate a typewriter is not an exact measure of physical effort. In the present tests, however, the operation on the different makes are so nearly alike that for comparative purposes the data given should be satisfactory from the point of view of fatigue as well as of work.

Acknowledgment

Practically all of the laboratory work for this investigation was carried out by Prof. L. H. Young of the Department of Physics at the Massachusetts Institute of Technology. The precision attained in these measurements is due to his careful and painstaking work in setting up and operating the special recording instruments used in this investigation.

# List of A.S.M.E. Transactions Papers Published Since January 1, 1928

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## MANAGEMENT



## MATERIALS HANDLING



## OIL AND GAS POWER



## PETROLEUM



## RAILROAD



## TEXTILES



## WOOD INDUSTRIES

# Progress in Materials Handling

## Contributed by the Materials-Handling Division

Executive Committee: R. H. McLain, *Chairman,* M. W. Potts, *Secretary,* J. A. Shepard, G. E. Hagemann, F. D. Campbell, and C. D. Bray

STURDY progress has been made during 1927 in the development of materials-handling equipment and in the application of that equipment to the needs of industrial plants, mines, construction, railroads, and marine carriers. While no outstanding advances are to be noted either in equipment design or use, there is no question but that the past year marks the active start of a transition period during which the business of materials handling will evolve from an empirical art into a scientific technique. Increasingly, profits, in materials handling must depend upon the precise fitting of equipment to the work to be done and to the coordination of the various handling units in a given installation in such manner that overall economies become maximum.

In the preparation of this report questionnaires have been circulated among several hundred concerns using materials-handling equipment, among practically all concerns whose business it is to design and to lay out plants, among representative builders of every recognized type of materials-handling equipment, among editors of representative industry publications, and among executive secretaries of industry associations. Equipment builders have been particularly helpful and have supplied your committee, not with propaganda, but with basic facts believed to be of value in recording progress of the year. Strangely, those concerns designing and specifying equipment for plants, both old and new, have failed to contribute anything whatever that is pertinent to this record. From each of the other groups questioned at least a few leaders have responded fully.

Approaching the subject first from the equipment point of view, we note that most developments have been in line with modern-equipment construction practice—whether for materials handling or for other purposes. Steel is coming into use in place of heavy castings, welding is supplanting riveting, simplification and exact machining for interchangeability of parts is becoming more common, improved bearing construction and better lubrication—these are basic trends.

With these developments in equipment, a better concept of the place of materials handling in production is reflected in—

1 Development of more effective organizations for materials handling, as at plants of the Otis Elevator Co., Westinghouse Electric & Manufacturing Co., Crompton & Knowles Loom Works, B. F. Goodrich Tire & Rubber Co., Hudson Motor Car Co., New York Central Railroad Shops—to mention but a few.

2 Building new plants around the transportation system rather than the transportation system around the plant—The Buick foundry, West Coast Porcelain plant, and A. O. Smith frame plant are cases in point.

As for particular developments in various types of materials-handling equipment, the following facts are significant.

### Cranes

Evidence of special effort to meet special conditions and requirements with an assembly of standard units built by quantity-production methods is notable. In addition to the general equipment trends noted above, that hold for cranes, the use of I-beams in place of expensive riveted box girders, the speeding up of light cranes, the reduction in size of electrical equipment and power drives, greater compactness of design securing lightness with strength, increased ease of operation, lubrication by oil baths and reservoirs abolishing the old grease cup—all of these changes are taking place. Crane manufacturers feel that users of this equipment should not be concerned with trick bearings, special limit switches, motors, and control apparatus which are being urged upon them by independent manufacturers not directly concerned with the building of materials-handling equipment.

Within the last six months another development is reported that is believed to open a big field for the effective use of crane equipment in wire mills. This is in connection with the cleaning house and baker. One company has developed a special cleaning-house crane with electrical equipment so arranged that acid and fumes from the acid cannot with any great degree attack the electrical equipment. This consists of a single-leg gantry crane with the motor located near the floor, and in connection with this scheme it is necessary to arrange the tubs in which the cleaning is done in what are called "straight" floors instead of circular floors with the old type of circular crane that is in use in practically all wire mills today. The first application of this device will shortly be made at the Bourne-Fuller Steel Company in Cleveland.

### Hoist and Tramrail Equipment

Fitting hoists and jib cranes to machine tools more extensively is considered significant. The installation of electrically controlled monorail switches at the Maytag Company's plant, representing a modification of an earlier installation at the Saco Lowell Shops, is considered by a firm of consultants in Detroit to be worthy of mention. The installation of remote-control equipment of this kind speeds up a monorail just as the automatic street-car switch, which is controlled by the motorman, speeded up the street car a few years ago. The use of electric hoists in connection with skid equipment moved by 10-ton-capacity electric trucks has made possible revolutionary changes in the method of handling sheet steel in and out of freight cars.

Proportional pressure control for brakes on large hoists used on mining machinery is reported to have been perfected during the year.

New applications of tramrail equipment are reported—as in the warehouse that arranges the split-package stock in the same order in which orders from the stores are written up. This is usually arranged up and down both sides of several aisles equipped with the tramrail system and with a rack adapted to take an ordinary warehouse truck. This truck is installed upon the rack, and three racks are hooked permanently in a train. The men filling orders walk along the aisles and the carriers are propelled by electricity along the rail at either 25 ft. per min. or 300 ft. per minute. The speed is fixed by means of push-button control.

A recent tramrail installation made at the plant of the Manchester Terminal Warehouse Company, Manchester, Texas, involves the use of 150 electrically propelled carriers that are sending four bales of cotton along the rail like a cash carrier

in a dry-goods store, eliminating the necessity of men traveling with each load. There are 17,000 ft. of rail involved on this system, and the rail is so arranged that there is no possibility of two carriers going in opposite directions colliding with each other, and it is also possible to get from any place in the receiving or shipping department and warehouse to any other place in the entire plant. This installation is causing considerable comment in the cotton warehouses of the South at the present time.

### Elevators

Increasingly, elevator equipment going into both old and new plants is being fitted to the transportation needs. Elevators capable of carrying a train of one electric tractor and 4 trailers to any floor of an 8-story building is typical of developments of this kind that are taking place. Micro drive for self-leveling elevators, while not a new development within the year, probably has won wider acceptance recently than ever before.

### Electric Industrial-Transportation Equipment

Storage-battery electric-truck manufacturers have widened equipment types available, and report an increasing sale of specially modified equipment engineered to meet precise service conditions. The use of live skids with lift trucks for handling freight in railroad l.c.l. service is reported to be on the increase. More high-capacity trucks are being built—from 5 to 10 tons—to meet the growing demand for the movement of heavier loads with fewer trips and hence with the expenditure of fewer man-hours. The Hudson Motor Car Co.'s materials-handling installation, around the use of 10-ton trucks, is pronounced by one disinterested authority to "excel what Ford has done." The perfection of the automatic coupler is another development of significance in connection with this type of equipment. This reduces personal injuries to workmen. In trailer design, aside from the new couplers, one definite development is the unit trailer employing a lifting device to raise reels of wire—holding them in the raised position during transport.

In the lift-truck field, a newcomer is noted in a unit to carry approximately 3000 lb., using a mechanical lifting mechanism actuated by the foot, while employing electric power in the usual manner of transport. This truck is designed to carry the 7-in. skid which has been developed for the older type of hand lift truck.

The most recent development by one company is an attachment to the crane truck. It consists of a heavy steel plate 30 in. wide, bent at an angle which is slightly acute and slidably mounted on a pair of steel channels which are attached at the upper end to the boom of the crane, and at the lower end to the coupler on the end of the truck. At the upper end of the steel plate and projecting from it is a curved plate-steel arm pivotably mounted. The hook of the crane cable is attached to the end of the arm nearest the steel plate which slides on the verticals. When the crane cable is wound up on its drum the strain raises the inner end of the arm and depresses the outer end so that it comes in contact with any article such as a roll of paper placed on the lower and horizontal portion of the bent plate, securely holding it in place while the plate slides up the vertical channels. By this simple device 1400-lb. rolls of newsprint paper are picked up where they have been landed on a pair of 2-in. × 6-in. planks placed just far enough apart to permit the horizontal portion of the bent plate to be inserted between them, and are carried to any point where the paper is to be stored. When lowered, the point of the bent plate touches the floor or a roll which has previously been placed. As soon as the tension on the crane cable is relieved a spring raises the arm, allowing this roll of paper to run down the bent plate and off into the position desired by the operator. By this means the truck operator, without assistance, can pick up, carry, and pile these awkward packages four high. When it is desired to use it as an ordinary elevating conveyor, the arm may be quickly removed and the crane cable attached directly to the end of the vertical portion of the bent plate. Means have been provided for adjusting the vertical members on which the bent plate slides so that various fixed angularities to the vertical may be obtained to suit varying commodities and conditions. In actual performance, ship's tackle raises two rolls at a draft. Two trucks equipped with cranes and paper-carrying attachments worked one hatch on a haul of about 350 ft. and less. The maximum performance was 104 rolls of paper per hour for the hatch, and nearly 100 rolls per hour average for the ship.

### Hand Lift Trucks

While there have been no radical changes in the design of portable elevators or lift trucks during the past year, the use of these forms of handling equipment has been extended to the solution of a wide range of handling problems. A very large percentage of the stackers now being furnished by the manufacturers are of special design, to meet special problems. Another distinct trend is toward the telescopic-frame type of portable elevator, which is suitable for use under balconies and low ceilings, and which may without any changes in the machine be extended in height so that it reaches to the ceiling of higher rooms of the plant. Another aid to the lift-truck method of handling has been the recent improvements which have been made in skid construction. Until comparatively recently the skids were made locally. Now, however, the lift-truck manufacturers have developed more durable and serviceable skids with steel frames. Because of the large number of skids made this phase of the industry now receives the attention which it deserves.

### Skid Shipment of Materials

Skid shipment of materials on an increasing scale represents a trend in handling that cannot be ignored. Improved tying methods for securing skids loaded with various commodities promise still further development of this system in new fields. Originally put to work in the paper industry, at least one notable new effort that has been successful has been putting skids to work between plants supplying railroads with supplies and their central storehouses. In turn, when these supplies are sent to line stores, the skid load is transferred intact. Mention is made elsewhere of the use of 10-ton electric lift trucks at the plant of the Hudson Motor Car Co. There fullest possible advantage is being taken of the economies to be derived through wider use of skids for handling materials in transit.

### Gasoline Truck and Tractor Equipment

In the field of gasoline equipment, a new gas-electric unit, designed for use in the battery compartment of a standard electric truck chassis, is to be noted. Improved characteristics for the unit, which is direct-connected instead of chain-connected, are claimed. For certain types of very rugged service as in forge shops, it is reported that the use of power units of this kind is being discontinued.

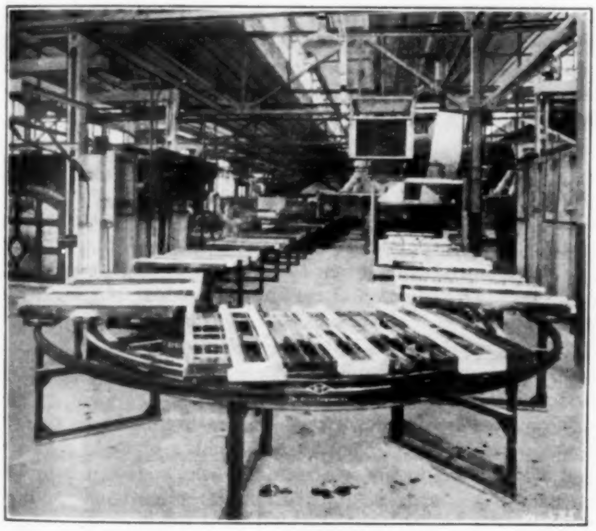
A new gasoline tractor of smaller dimensions for work in narrow aisles and for inside haulage, equipped with a so-called condensing silencer, has been introduced, which is said by its manufacturer to be capable of 24-hour service with remarkable economy.

### Conveyors

Idlers for belt conveyors have been improved, mainly through the perfection of bearings. Improved casings for elevating

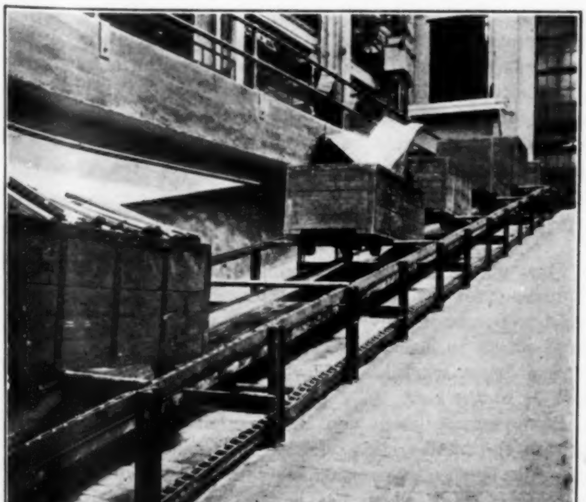
Loading Point for Tramrail System in Cotton Warehouse

Electric Truck Handling Skid Shipment

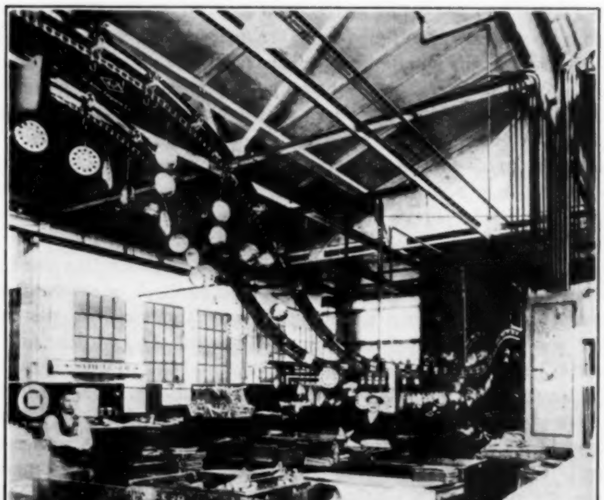


Carrousel Conveyor

Dust-Proof Gravity Roller Conveyor in Foundry



Chain Conveyor for Hand Trucks



Trolley Conveyor Using Link Chain

conveyors are noted. Chains and other conveyor parts to resist acid and alkaline atmospheres are in course of development. (This incidentally holds for the materials used in the construction of most types of materials-handling equipment.)

Particularly important developments have taken place during the year in the underground conveying of coal. Mechanical loaders for working at the room face are making it possible to maintain a given production with a much smaller number of rooms.

Use of single conveyor lines for carrying products of varying size is noted. Increased employment of overhead chain-type conveyors also is noted.

### Pneumatic Equipment

A type of pneumatic conveyor which has been built commercially somewhat less than a year has produced results which show important economies over other types of pneumatic or steam conveyors. As is the case with any new equipment, it was necessary to overcome difficulties, correct errors in construction, and make substitutions of materials and alterations for convenience of operation. A very recent test conducted in a plant having four 500-hp. boilers shows very satisfactory results.

The ashes at this plant are extremely variable in character due to the fact that wood refuse is burned under two of the boilers, while the other two are fired with a mixture of wood refuse and coal. In addition to the above, crating, boxes, etc. are broken up, and with the nails, form a rather heavy ash. Also there are a large number of sanding machines in the plant, and the fine wood refuse contains a considerable amount of sand which fuses with the ash in the furnace. This forms a hard, glass-like slag, which weighs about 135 to 140 lb. per cu. ft. Therefore the material to be handled ranges from light, fine, fluffy ashes to heavy slag weighing up to a maximum of 140 lb. per cu. ft. All of this material is handled through a duct having an internal diameter of 5.75 in. Tests conducted on this installation show an average capacity of about 13 to 15 tons per hour, with a steam consumption of about 240 lb. per ton of materials handled.

## INDUSTRY DEVELOPMENTS

### Layout Studied in Paper Industry

The layout of the modern pulp and paper mill has been getting a great deal of study by the industry in an endeavor to reduce to a minimum the labor in handling raw products. The entire plant has been so designed that the materials flow in a logical manner from the raw product to the finished commodity. This has involved considerable handling equipment, and perhaps the best example of the modern mill is the new Gatineau Plant of the Canadian International Paper Company. Provision has been made at this plant for adequate storage of pulpwood, sulphur, lime, and other materials, and the conveying systems from storage to the mill are well arranged and allow for future expansion.

Pulpwood handling has been given much consideration during the last year and a half, and several new methods of mechanical conveyance have been adopted. One of the most interesting is the new loading and unloading equipment used by the Anticosti Corporation for handling 4-ft. pulpwood to and from vessels. This equipment consists of a pulpwood grab or "trapper," which is lowered into a restricted basin filled with 4-ft. pulpwood. The load is transferred to the hold of the vessel, where it is tiered up. The unloading procedure is carried on in the reverse manner, by means of a platform which will hold about one cord, and this is lifted from the hold of the ship and dumped into a conveyor. This equipment makes it possible to load and unload pulpwood many times faster than by the old methods, and the cost of handling is substantially reduced.

Recently equipment has been developed to handle long logs by the use of a sling arrangement. This eliminates the necessity of cutting them into 4-ft. lengths, and speeds up the loading and unloading operations both from cars and vessels.

The use of air to handle granular material such as clay, sulphur, and lime has been adopted by a number of mills in the pulp and paper industry. The cost of handling is reduced, and, what is more important, the dust in handling is practically eliminated, thus giving the workmen a great deal more comfort in unloading such materials from cars.

Air conveying equipment for chips and semi-dry pulp has also been developed and adopted in some particular cases.

The electric lift truck is being more commonly adopted by the pulp and paper industry for a number of commodities such as lap pulp, pulpwood, paper, and similar materials that are piled on platforms. This method eliminates considerable handling, and in the case of finished paper reduces the damage of spoilage due to poor handling methods. The overhead crane has enabled many mills to solve the handling problems when such materials as baled paper, rags, and similar products are used. This equipment is also used by a number of the mills to handle finished and semi-finished paper, and although it is not essentially new, the mechanical principles involved are being used to a better advantage than several years ago.

### Foundry Practice Developing

A general trend toward mechanization, which started perhaps 15 years ago, has been accentuated by highly competitive conditions among foundries. Mechanical handling, covering sand, fuel, metal, and finished castings, has made tremendous advances. The adoption of continuous molding, melting, pouring, cooling, and shake-out has greatly decreased the cost and increased the production of the larger plants producing a standard line. The continuous pouring system does not apply, however, to small or jobbing foundries.

A radiator foundry reports 50 per cent saving in floor space, a reduction of 75 per cent in the number of flasks required, and that the production per man has been increased from 5.75 molds of one class to 9.70 of the same type per hour, and from 18.25 to 30.55 molds per man-hour on a smaller hob.

Every new foundry built and every shop which has revised its equipment has gone the limit on conveying and handling equipment during the past 18 months.

Improvement in quality of product and increased pressure on merchandising methods probably will have the major attention of foundry executives in the next few years. Cutting corners on production costs, and improvements in manufacturing methods along present known lines, probably have reached the high point, although many establishments still could apply these factors to existing practice.

### The Construction Field

Most of the motor-truck manufacturers are building special equipment for road-building operations. These include special-sized bodies, bodies divided into batch compartments, and wide-tired wheels to decrease the unit weight on the road subgrade. In one case a truck has been developed which dumps to either side or to the rear.

Power-shovel design and construction have recently turned toward the smaller sizes of shovels, $^1/_2$ and $^3/_4$ yd. capacity, resulting in speed, operating mobility, and adaption to a large volume of work which has heretofore been uneconomical for large-shovel operation. On gasoline shovels, air-operated

clutches are contributing to flexibility of operation. Somewhat along the same line air engines are being used direct-connected to the crowding and swinging motions of one shovel.

On all construction equipment steel castings have been replacing cast iron and riveted structural steel. In the past year extremely large unit steel castings have been used on some equipment. In one case a power shovel uses a single steel casting for the entire body frame and the bearing supports for all of the main bearings.

Roller and ball bearings are becoming standard equipment. At the 1927 road show of the American Road Builders Association, fully 50 per cent of the machines exhibited were equipped with such bearings. Of the other bearings used on construction machines, most of them are bronze-bushed, and practically all are of the split type to facilitate easy adjustment.

Much activity has been evident in lubrication development. Pressure systems of the Alemite and the Dot type are becoming commonplace. A more recent development is the use of totally enclosed gears running in oil.

A hoist manufacturer has developed a three-speed hoist using a motor-truck-type transmission. Portable conveyors, both of the belt and bucket type, and belt-conveyor installations for handling stone, cement, and other construction material, are continually being adapted to new construction uses.

### The Railway Field

The applications of materials-handling machinery and devices in the railroad field are so diversified and extensive that it is held by one close to the situation almost impossible to give any summary as to the progress which has been made with any degree of accuracy. It is known that in each department there has been a steady increase in materials-handling devices and equipment in the interest of increased efficiency and greater economy of operation. As far as is known, there have been no startling improvements adopted on an extensive scale in any of the departments. The progress has been more in the extended and greater use of equipment and methods which were adopted by the more progressive roads in recent years.

In connection with materials handling in the railroad field, reference may be made to the fairly recent utterance of an authority close to present methods of freight handling. He pointed out that long-haul profits are being needlessly sacrificed in the terminal handling of freight, estimating that a saving of $25,000-000 is possible through the fully effective use of mechanical freight-handling facilities already at the disposal of railroads.

Skid shipment, already alluded to, represents an important development certain to be more widely practiced in the future.

Another change in railroad practice that already has come in some sections of the country, is store-door delivery. This will involve a tremendous expenditure in new short-haul materials transportation, and because of the experience of the American Express Co., which is the largest user of electric street trucks in the world, it is believed that this may become a recognized type of equipment in this branch of railway service.

### Marine Handling

The most significant development in marine terminals during the past year, at least on the Pacific Coast, has been the remarkable increase in the percentage of shipments handled to and from such terminals by trucks and the decreasing percentage handled by rail. As shown by a paper read before the Pacific Coast Association of Port Authorities by Harbor Engineer Nicholson of Los Angeles, the future piers of Los Angeles Harbor will have to be designed to accommodate 60 per cent or more of the traffic being handled by trucks. The same ratio of truck traffic is being approached in San Francisco, Seattle, and Portland. If this increase continues it may mean the redesigning and rebuilding of every pier on the Pacific Coast, and will certainly mean the introduction into pier sheds of a far more comprehensive system of mechanical handling than at present prevails.

At least one new experimental machinery installation has been made on the Pacific Coast which may lead to a large introduction of such machinery. On the passenger and freight steamer *City of Honolulu* there has been introduced a conveyor system for handling general freight from side ports through hatches of the lower decks and into the hold spaces. Initial trips of this vessel indicate that this method of handling freight on combination passenger and freight steamers will be highly successful. Tests during the first trip indicated an overall saving of some 30 per cent as compared with ship's winches and tackle in the handling of pineapples in cases.

It is altogether likely that the development trend in materials-handling machinery at marine terminals for Pacific Coast use will have to be directed toward a condition catering to truck transport.

### The Ceramic Industries

For several years the common brick plants have experimented with cranes whereby they could progress the brick through drying and firing in units of from 2 to 500. This has involved the devising of kilns with removable crowns. In this system the bricks are kept in blocks of 2 to 500 throughout the process, even to the loading on to the cars or barges. The extension of this principle to brick manufacturing in general would result in great improvements and economies.

The most important development in pottery plants has been the tunnel kiln, in which the pottery products are fired while in constant motion through a long tunnel, the heat being applied at the middle of the kiln.

Other developments in materials handling have affected this industry chiefly from the standpoint of transporting the raw materials and unfinished and finished products by means of belt conveyors. Driers with automatic heat and humidity control and suitable conveying systems have come into use quite extensively.

The principal development of the future will be in the still greater application of continuous firing systems and continuous movement of the ware through the several processes, in the opinion of an authority close to the industry.

Summarizing, developments of note include:

Tendency to better organization within the plant for the control of materials-handling equipment

Tendency to handle heavier loads fewer times

Tendency to move material direct from freight cars to production machines instead of into raw-materials stores

Tendency to reduce the amount of work in process and the storage reservoirs of partly or wholly finished parts

Tendency to tie the materials-handling system directly into that used for production

Tendency to modernize facilities for handling in smaller plants, and in plants where comparatively low tonnages have to be transported.

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# Sugar-Warehouse Conveying Systems

By JOSEPH T. BUZZO,[1] SAN FRANCISCO, CALIF.

*In this paper the author describes conveying equipment installed at the Crockett, Calif., plant of the California and Hawaiian Sugar Refining Corp. First, a general description of the plant layout is given, together with an explanation of certain conditions which demand large storage facilities for both raw and refined sugar. Among the types of conveyors described are belt conveyors, depressed floor conveyors, slat conveyors, a specially designed screw conveyor, and various portable and semi-portable conveyors. The duty to be performed by each of these types is mentioned, and the maintenance problem is discussed. An interesting weighing conveyor, which receives the bagged sugar directly from the steamer, is described. A part of the paper deals in an explanatory manner with the very interesting central-control board, through which the entire system is under instant control. An interesting comparison of manual and conveyor handling is given, with the figures well in favor of the latter method.*

CROCKETT, Calif., is situated about thirty miles east of San Francisco on Carquinez Straits, the connecting link between San Pablo and Suisun Bays. The plant of the California and Hawaiian Sugar Refining Corporation has at Crockett an ideal manufacturing location, for here, literally, "rail and water meet." Along a water frontage of approximately 3000 ft. there is a depth of 40 to 50 ft., and vessels may safely dock at any point for receiving or discharging cargoes. The main line of the Southern Pacific Company runs on the south side of the refinery, where there are ample facilities for switching and for loading and shipping the finished product.

The main warehouse, 870 ft. long by 290 ft. wide, and the auxiliary warehouse, 320 by 160 ft., have a combined storage capacity of 135,000 tons of sugar. Such extensive storage facilities are required because of special conditions surrounding the company's business. Into these warehouses is gathered the raw sugar from 31 Hawaiian plantations. With the exception of a short shut down at the end of the year, for overhauling, the refinery operates continuously at a uniform rate of 2200 to 2400 tons per day. The plantations, however, produce the raw sugar during a much shorter season, governed by the ripening of the cane, and the resulting accumulation of raws must be stored for subsequent refining. Also, in order to secure the minimum manufacturing cost, the refinery, as mentioned, operates at a uniform rate throughout the year. Therefore storage space must be provided for refined sugar when the market fails to absorb it as rapidly as it is produced.

The incoming raw sugar may be sent direct from dock to refinery or into the warehouse for storage, whence later it must be transferred to the refinery. The finished product must in turn be delivered to the warehouse either for direct shipment or into storage for subsequent shipment by rail or water. The economical accomplishment of these various manipulations calls for a comprehensive conveying system of great flexibility. It is the province of this paper to offer a brief description of the manner in which the company has worked out this problem.

## General Arrangement of Conveyors

It is difficult to concisely describe the system with its interlocking features so that the arrangement may be clearly grasped. A study of Fig. 1, which is an ideal cross section of the main warehouse, will greatly assist. Broadly, there is a complete system for transferring within the warehouse, this system being connected to the refinery by two belt conveyors which serve the double purpose of taking the raw sugar to the refinery and of returning the refined product to the warehouse system for distribution to storage or to shipping points. In addition, a separate conveying system is provided for transporting barrels and boxes to the warehouse.

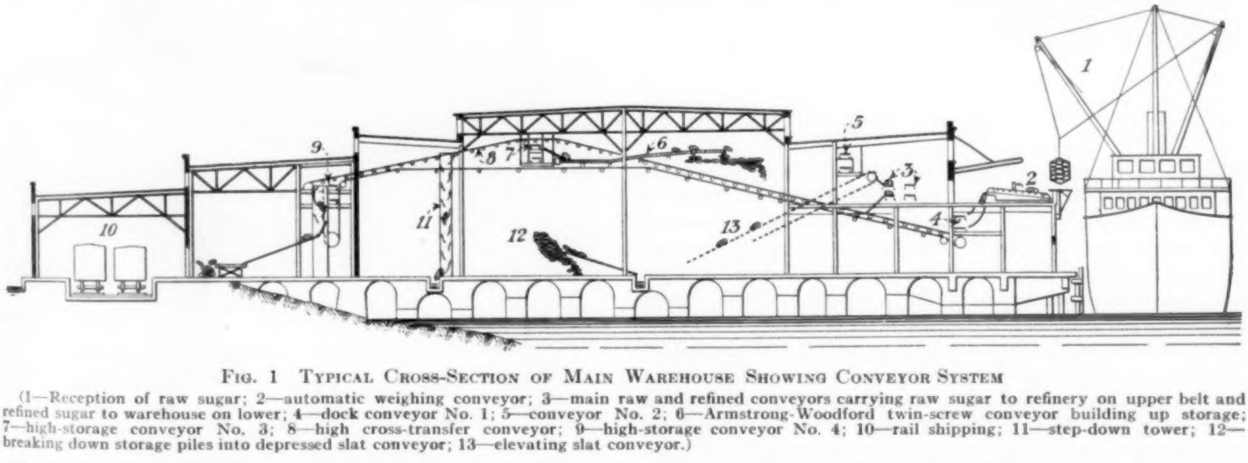


Fig. 1 Typical Cross-Section of Main Warehouse Showing Conveyor System

(1—Reception of raw sugar; 2—automatic weighing conveyor; 3—main raw and refined conveyors carrying raw sugar to refinery on upper belt and refined sugar to warehouse on lower; 4—dock conveyor No. 1; 5—conveyor No. 2; 6—Armstrong-Woodford twin-screw conveyor building up storage; 7—high-storage conveyor No. 3; 8—high cross-transfer conveyor; 9—high-storage conveyor No. 4; 10—rail shipping; 11—step-down tower; 12—breaking down storage piles into depressed slat conveyor; 13—elevating slat conveyor.)

Within the warehouse there are four belt conveyors and two depressed floor slat conveyors running from one end to the other. These are in turn served by four cross-belts, two inclined slat conveyors, and miscellaneous portable or semi-portable conveyors, chutes, etc., which transfer the product from one to another of the main units.

Conveyor No. 1 (Fig. 1), known as the "dock conveyor," located just below the second floor on the water front, receives the raw sugar from the steamers. It is arranged so that both the upper and the lower, or return side, may be used, thus providing transfer in both directions. All of the main belt conveyors are designed in this same way to convey simultaneously on either the upper or the return side of the belt.

Conveyor No. 2 is used primarily for the refined product and

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delivers to any desired point along the waterfront, either for trucking to the steamers or for storage on the first and second floors. In emergency it may also be used for the transfer of raw sugar leading to the refinery or to storage on the second floor.

Conveyor No. 3, known as the "high-storage conveyor," is used for delivering either raw or refined sugar to storage piles.

Conveyor No. 4 is for distribution of the finished product for rail shipments.

The two depressed floor slat conveyors gather raw sugar from storage and by inclined slat conveyors elevate to what are called the "main raw and refined conveyors," which lead to and from the refinery.

### Control

Fig. 2 is a view of that section of the warehouse where the system converges for delivery to the two main raw and refined conveyors leading to the refinery. At this point a "control operator" is placed. His station is located at a strategic point where he has an uninterrupted view of all the conveyors in this section, supplemented by telephone and bell-signal communication with all parts of the warehouse. Here the entire system of 32 individual units is under remote control. The specially designed control board is shown in Fig. 3. On the bench are located remote-control start and stop switches for all units. These control automatic starters of the transformer and "across-the-line" type, mounted on centrally located panel boards in each section of the warehouse. At each switch a red light shows operation or a green light indicates that the conveyor is idle. Specially marked rubber caps, fitting over the remote-control buttons, indicate the combination of conveyors in a complete train. Above the bench are the signal and instrument panels. The operating signals are given by colored lights behind transparencies supplemented with bell alarms. Throughout the conveying system are emergency-stop push buttons. When a unit is so stopped a red light automatically illuminates the transparency for that unit and a bell alarm sounds. Also, the red light on the bench goes out and the green light comes on. To prevent blockades, the control operator immediately stops the other conveyors which feed this unit and stands by ready to restore operation on signal. In case a motor kicks out through overload, the transparency takes a green illumination and a bell alarm sounds.

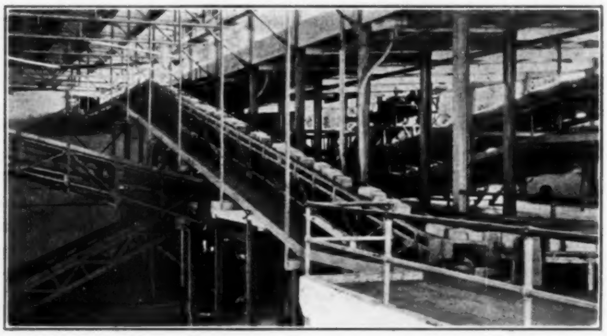

Fig. 2 Principal Junction Point of Conveyors in Warehouse
(Left, elevating slat conveyors and high cross-belts; center, specialty conveyor carrying boxes; right, raw and refined belts running to and from refinery.)

Provision is made on the panels for adding ammeters which will act for the control operator as indicators to show normal and abnormal operation, and make it possible to arrange for the correction of improper conditions before serious trouble develops.

Wherever possible, belt conveyors are used in preference to the slat design. These have untroughed belts 36 in. wide, a width which permits the bags to lie in any position. The belts are seven-ply with best quality friction or cement, and are finished with $^3/_{64}$-in. rubber cover, both sides. The fabric is special 32-oz. duck, having, per inch, 26 strands of eight cords each in the warp and 16 strands of five cords each in the filler.

Extensions to the system have been added from year to year, and it has been the practice to place the new belting on the most severe service, transferring the used belting to a lighter duty. This has so prolonged the life that there has been no discard and the oldest belt has now been in continuous service over twenty years. With the completion of the system, however, replacements will become necessary.

### Belt Conveyors

The longest conveyor is about 800 ft. between pulleys, with an actual belt length of 1724 ft. The operating speed is about 250 ft. per min., determined by operating conditions and not by the carrying capacity of the conveyors. So far it has been impossible to provide a continuous stream of bags, owing to the fact that delivery from the steamer holds it in batches. A speed beyond the theoretical is, therefore, required to properly space the bags from these batches. Also, at the speeds employed, the bags are switched off the belts with minimum difficulty.

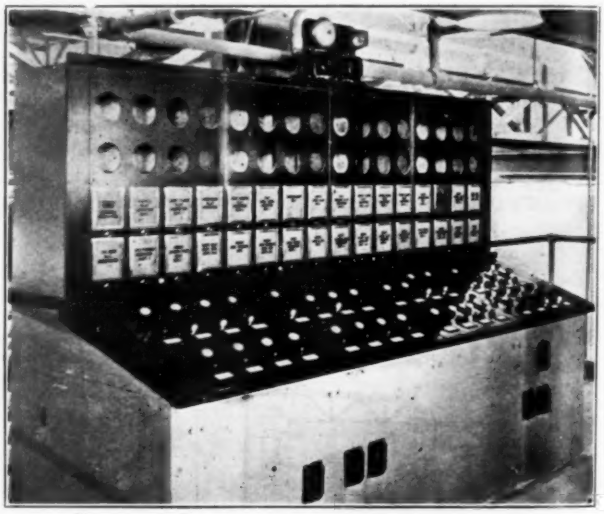

Fig. 3 The Control Board

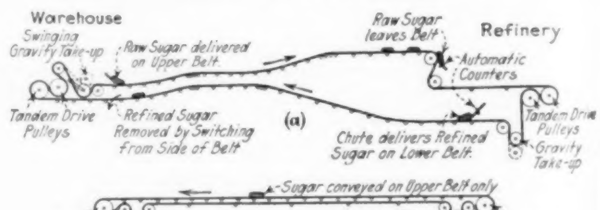


Fig. 4 Diagrams of Belt Conveyors Illustrating Two Arrangements for Gravity Take-Up
(a) Raw and refined conveyors, typical of belts traveling in one direction and conveying both ways simultaneously.
(b) Reversible belt conveyor with drive and take-up at both ends.

The longer belts are driven at both ends with the two motors electrically interconnected and, for heavy drives, rubber-covered drive pulleys are provided in tandem. The length of the belts

is affected by weather conditions. To compensate for this, and especially to take care of the elongation at starting, gravity take-ups are installed. On belts running in only one direction these are placed (see Fig. 4) at the points of least tension, on the upper side at one end and on the return side at the opposite end. On reversible belts both take-ups are located on the lower side and only one functions, depending upon the direction of travel.

The belts are supported on plain rollers with hardwood blocks for bearings. Because of the thousands of rollers involved, an extensive investigation has been made to compare the standard with the ball-bearing types. While the latter were, of course, more economical as to power consumption, they failed to stand up under severe service. Although the hardwood bearings give no trouble and are exceedingly cheap, it is debatable whether metal journals would not be superior.

With the system under discussion, it is, in many cases, necessary to switch containers from the belts. This is accomplished by means of a board diagonally disposed over the belt. When in a raised position the bags may pass through, but they are pushed off when the switch is lowered. Brands which are to go to different destinations are sorted on the conveyors by means of these switches.

### Slat-Type Conveyors

In the case of the depressed floor conveyors and inclined elevators, the belt design would be impracticable, and the slat type is used. Wooden slats 30 in. long by $3\frac{1}{2}$ in. by $1\frac{3}{8}$ in. are bolted to two strands of No. 212 Griplock roller chain which travel in angle-iron tracks. For strength and freedom from splintering, the slats are made of hardwood. As there is little stretch, short take-ups are suitable. Adjustments can also be easily secured by removal of a slat with its attachment links. In the case of the depressed conveyors a single scraper projecting beyond the surface of the slats automatically prevents accumulation in the pits of spillage from broken raw-sugar bags. This is scraped to the tail pit from which it is readily removed.

On the incline conveyors, three consecutive slats in each group of ten are of steel plate, affording a depression so that the following wooden slat acts as a lifter. With this design a 50 per cent inclination is practicable.

Slat conveyors for given lengths consume much more power than does the belt design. The longest conveyor, with the type of chain on which this company standardizes, is 300 ft. between centers, and a 20-hp. motor is required.

### Discharging Cargo

Seventeen vessels of the Matson Navigation Company bring the raw sugar to Crockett from the Hawaiian Islands. The largest of the fleet are the sister ships, *Manukai* and *Manulani*, which carry 14,000 tons each. Discharge is by slings of fifteen bags, or from 1500 to 1900 lb. The loads are dropped on stevedores' tables on the upper deck of the dock (see Fig. 1). Formerly all bags were hand trucked from this point over platform scales to the conveyor. With this method of discharge, 20 truckers per hatch could handle but 675 tons in eight hours.

### Conveyor Scales

Three years ago specially designed conveyor scales were developed and installed, and now one man replaces the 20 truckers. At the same time, the rate of discharge, due principally to the use of these conveyor scales, has increased from 675 to 1000 tons. The total crew for a hatch consists of 22 men. On shore there are six table men, two weighers, and one switchman; on the steamer, a foreman, a winch driver, a hatch tender, and ten stevedores in the hold. These scales are shown in Fig. 5. Four units of two scales each are installed. Usually, however, discharge is from two hatches only, and never from more than three. The conveyor is mounted on a platform scale which in turn is carried by a steel frame work fitted with car wheels. Tracks laid along the dock make it possible to shift the units, for spotting opposite ship's hatches. Each unit is provided with jacks for accurately leveling the scale. Provision is made for quickly taking scale checks. A set of test weights is so mounted that by moving a lever they may be placed on the scale or removed. A revolving brush cleans the belt, immediately removing all loose sugar spillage; otherwise the accuracy of the weighing would be impaired. The design permits taking weights in transit, although with a push button control the operator can, when necessary, stop within a few inches. Careful checking has conclusively proved the accuracy of this method of weighing, and the weights are accepted by both the refinery and the plantations as the basis for purchase.

Fig. 5 Duplex Scale Conveyor with Canopy Removed

### Progress of Material Through Plant

The raw sugar required for immediate process is delivered by the conveyor direct to the refinery, and the balance goes to storage. The switchman working at the end of the scale conveyors operates a chute to divide the bags between the upper and lower sides of the dock conveyor, No. 1, Fig. 1, for the refinery and storage, respectively.

The bags on the upper belt are switched to a cross-conveyor, from which they are delivered to one or the other of the depressed-slat conveyors, thence by way of the inclined slats to the main raw and refined belts leading into the refinery.

This is the standard routing of the sugar, although in emergencies, caused for example by the shut down of a unit, there are several other combinations of conveyors which can be used. It is even possible to reach either of the main raw and refined conveyors entirely by the belt system and without the use of the depressed floor slats.

The raw-refined conveyors are so named because they carry raw sugar on the upper side to the refinery, and on the lower side return the refined product to the warehouses. Fig. 4 shows in outline the plan of these conveyors. Duplicate installation minimizes the danger of complete stoppage of the flow of sugar, which if prolonged would be followed by a costly shutdown of the plant. In actual fact, however, as a result of rugged construction and careful maintenance, it has never been necessary to shut down either unit for more than an hour or two.

Each belt conveyor discharges its load of bags to the refinery upon what is known as the "cut-in conveyor." This is a slat conveyor placed at table height over a large storage bin covered with steel grating. Workmen along these slat conveyors open these bags and empty them through the grating into the bin.

All of the raw bags are automatically counted by an electric

counter as they leave the belt conveyor. The discharge chute leading to the cut-in conveyor is fitted with a trigger which is deflected by each passing bag. This trigger actuates the electric contacts by means of a shaft and cam which is returned to the open position by a spring. In order to avoid chattering, due to rebounds which would result in double count, an electromagnet is used. The magnetic circuit is completed through the cam which acts as an armature.

Thus the bags which are placed by the stevedores on the scale conveyors at the dock travel a distance of 1500 to 1600 feet with no manual handling until they reach the cut-in conveyors at the refinery.

Those bags of raw sugar which are to go into storage are sent by the switchman at the end of the conveyor scales to the lower side of the dock conveyor, No. 1, Fig. 1, from which they are in turn transferred by one of the high cross-belts to the main-

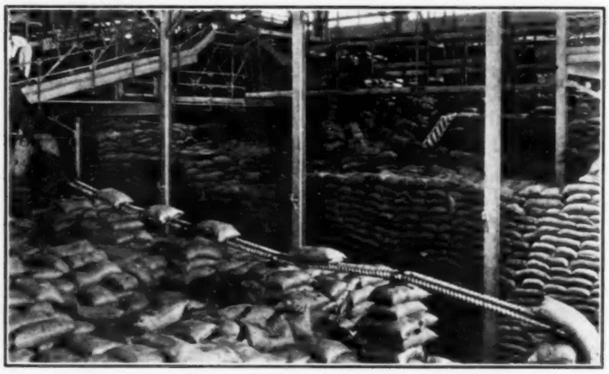

Fig. 6 Armstrong-Woodford Twin-Screw Conveyor
(Conveying from high cross-conveyor to storage pile at upper right—high-storage conveyor.)

storage conveyor, No. 3, Fig. 1. At the desired destination they are switched off and by chute or portable conveyor carried to the proper point for placing into the storage pile by hand. These piles are carried seventy bags high, about forty feet, the bags being placed in an orderly manner to secure a rectangular pile, to which stability is given by making every fifth course a header.

## Twin-Screw Conveyor

Fig. 6 shows raw sugar going into a storage with the use of a special portable conveyor, the patented invention of two of the Company's engineers. In this machine, known as the Armstrong-Woodford twin-screw conveyor, two parallel members of light tubing wound with a coarse-pitched right- and left-hand thread perform the carrying operations. Sections 8 ft. long and connected at bearing points by universal joints, permit positioning over irregular surfaces. The drive end consists of a motor with a double right and left worm-gear set. The two screws operate at 200 r.p.m., rotating inward, and convey at the rate of 100 ft. per min. Sections weigh but 55 lb. each, and the length can be increased quickly and easily, a section at a time, from 8 ft. minimum to 60 ft. or more. The conveyor will deliver downward at almost any angle and will elevate at from 20 to 40 deg., depending upon the shape and pitch of the thread. On sugar piling, two of these units have saved five men.

## Chutes and Step Towers

In Fig. 6 the bags are shown being delivered to the twin-screw conveyor by a wooden chute. The elevation of the high-storage conveyor is 36 ft. above the floor level. In starting sugar piles and also for transferring from the high conveyor to floor conveyors, the use of such chutes is awkward and space-consuming. Spiral conveyors have been used, and for fixed installations are preferable to the straight chutes as they require less floor space. This design has been abandoned, however, except for handling barrels and boxes. In Fig. 7 may be seen a canvas tube which is serviceable and has the advantage of light weight. After considerable experimental investigation, however, the company is gradually standardizing on "step towers," one of which is indicated in Fig. 1. This type has been used in other industries, both for the lowering of loose material, such as coal and rock, and also for sacked material. It consists essentially of curved baffles alternately opposed and mounted in a substantial framework. This appliance overcomes many of the objectionable features of the other types. It occupies little floor space and the baffles so check the acceleration of the falling bags that, in a drop of 30 feet, the speed is not perceptibly increased.

In completing a storage pile it is the present custom to leave, at the top, a channel wide enough to receive a straight wooden chute. When the pile is to be torn down, chutes are placed so as to deliver the bags to the depressed floor conveyors for delivery to the refinery in the same manner as has been described. The chutes may terminate in a portable conveyor in order to reach the

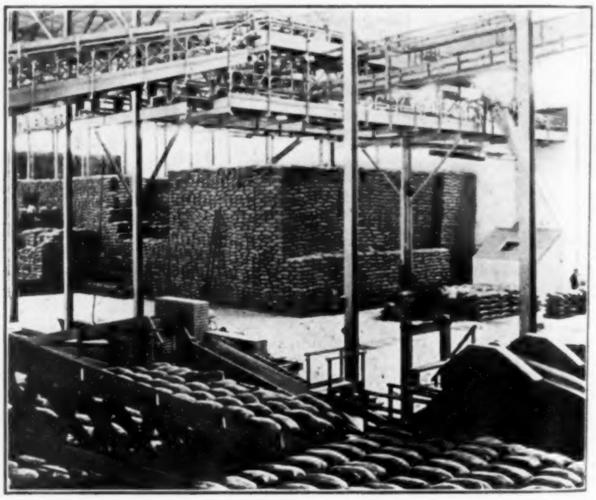

Fig. 7 Sugar in Storage
(Above, junction of high cross and high-storage belts; below, depressed conveyor delivering to inclined slat conveyor; right, canvas tube for lowering bags from overhead conveyors.)

depressed floor conveyor, and when the grade becomes too low the removal may be completed entirely with portable conveyors or by trucking.

Aside from the fact that with this method a few men can handle a considerable tonnage, the company believes it has little merit. By constant investigation, the company seeks improved methods which may not only be more efficient but which will also result in less damage to containers and will be less hazardous to the employee.

Having discussed the transfer of raw sugar from the steamer, both to the refinery and into storage, with subsequent transfer to the refinery, the author will now pass to the handling of the refined product.

## Handling the Finished Product

The last refinery operation is the sewing of the bags. Chutes convey these to the return side of the main raw and refined conveyors, from which they may be sent to one of four destinations. For water shipment, transfer to the dock conveyor, No. 1, Fig. 1, permits distribution for direct trucking to steamers or

barges, or the sugar may be transferred to conveyor No. 2 for preliminary storage at any point along the water front, on the first or second floor. By high cross-conveyors, Fig. 7, it may be transferred to the high-storage conveyor and delivered, as in the case of the raw sugar, into high-storage piles. Finally, by the same high-cross conveyors, it may be transferred to conveyor No. 4, Fig. 1, by which distribution is made through the train shed, either for preliminary storage or directly to freight cars.

Breaking down refined sugar piles is accomplished in the same manner as with the raw sugar, excepting that more care is exercised to prevent breaking of containers.

The entire discussion so far has been confined to the handling of sugar in bags. This applies to all of the incoming raws and to about 88 per cent of the finished product. The balance of the output is shipped in barrels, half barrels, boxes, and cartons, the latter packed in wooden cases For the transportation of the sugar in these hard containers an entirely independent installation is required, which, however, possesses no especially novel features. Part of the system may be seen in Fig. 2. For those straight-line sections which are nearly horizontal or are inclined upward, power-driven slat conveyors are used. Where the path changes direction, or is downward with a sufficient gradient, ball-bearing roller conveyors are used, and spirals are installed for dropping from one floor to another. Gravity systems, for the best results, should of course be designed for the particular shape and weight of package to be transported. However, the individual quantities to be handled at the refinery are too small to justify separate conveying installations, and therefore all are handled with reasonable satisfaction on the single system described in the preceding pages.

## Conclusions

While many features, both of equipment and methods, which have been briefly discussed in the foregoing paper, are no doubt adaptable to other similar fields, nevertheless, the conditions as a whole at Crockett are so peculiar to this plant that any cost data would be meaningless.

The main conveying systems have proved, generally, most satisfactory. The products are transferred easily and, because of the distances involved, it is believed at a lower cost than would be met with any other mode of transportation. Special auxiliary equipment which has been developed, such as the step towers, twin-screw conveyors, conveying scales, etc., have proved their worth. However, the company and its engineers consider that there is a great opportunity for further economy in handling the products after they leave the main conveying systems. With the practical completion of an extensive construction program which has occupied a period of years, it is now possible to give more concentrated attention to the refinements of this work.

Economies may probably be secured through a more extended application of the twin-screw conveyor and of the step tower. A portable type of step tower used in combination with the twin-screw conveyor may prove of much value in building up and tearing down storage piles. In these and other ways it is expected that appreciable economies may be realized, and the engineering department in cooperation with the warehouse department is carefully investigating this attractive field.

# Operating Costs of Electric Industrial Trucks and Tractors

By C. B. CROCKETT[1] and H. J. PAYNE,[1] NEW YORK, N. Y.

*The authors attempt to show how direct and indirect costs of a materials-handling system may be classified and estimated, and apply the methods described to the question of operation of electric trucks. The direct costs of operation are here divided into fixed charges and operating charges, both of which are enumerated and, where possible, estimated. Factors affecting the costs are likewise enumerated, and actual figures of cost of operation taken from several plants are presented, and the savings due to truck operation pointed out.*

THIS paper has been prepared to present outstanding economic features of the subject. The authors have attempted to define the different costs as they are most generally accepted in industrial plants, to reproduce fair average figures from actual performance data, and to set forth sufficient actual records to illustrate the effect upon costs of varying plant conditions.

The subject of indirect costs and savings is briefly discussed, and the major items are identified so that executives considering the purchase of new equipment may find here data that are of direct value in explaining the factors to be considered.

Underlying the use of the electric industrial truck or tractor is the fundamental principle which has characterized the phenomenal growth of America's manufacturing business, the principle of the maximum use of mechanical energy for every wage earner. Figures recently published by the Government Bureau of Foreign and Domestic Commerce reveal that since 1870 the value *per worker* added to goods by manufacture has increased 397 per cent, while the mechanical energy available per worker has increased 371 per cent.

Increased production goes hand in hand with the application of mechanical energy to manufacture.

Modern management applies the searchlight of cost accounting on manufacturing processes and the handling of material in the plant alike. Uniformity of work, however, and similarity of conditions characterize the manufacturing process but are conspicuous by their absence in the field of materials handling. Net yearly cost per unit moved is the goal which has been set, but that goal is difficult and well-nigh impossible of attainment. Costs per foot-pound or ton-mile moved are theoretically the most desirable, but practical limitations have made the cost per ton moved, cost per load moved, or cost per day more generally accepted units.

Costs of any mobile materials-handling system may be generally classified as "direct" and "indirect," and must be given equal consideration. The direct charges, both fixed and operating, are those incurred in the operation of the system itself. The indirect costs are those incurred in other processes or departments but which are influenced by and attributed to the materials-handling system.

The direct costs of operation of electric trucks may be divided into "fixed charges" and "operating charges."

The first group, assuming proper maintenance and properly chosen equipment, are independent of the type of work or number of hours used per day unless it be a question of 8- or 24-hour service, in which latter case depreciation will of course be more rapid.

The fixed charges are easily defined and hence readily available. They include:

1 *Depreciation on Truck or Tractor* is almost always the cost of the truck or tractor divided by the estimated life and charged off periodically. Truck and tractor prices vary from $1100 to $3800 with average lives of 8 to 14 years, the resulting average depreciation charges being about $300 yearly.

2 *Depreciation on Storage Battery* is arrived at in the same manner as for the truck, a time basis being used. First costs of batteries vary from $250 to $1500, with a life dependent upon the type selected. Average depreciation charges may be taken as $200.

3 *Depreciation on Charging Equipment* is similar to the items above, costs varying from $150 to $300 with lives of 15 to 20 years. Annual charges average $10 to $15.

4 *Interest, Insurance, and Storage Charges* for the above are usually grouped and figured as a straight per cent yearly on the first cost of the equipment. This figure is generally taken as 7 per cent, being 4 per cent for insurance and taxes, and 6 per cent interest less 3 per cent interest on depreciation reserve.

Operating expenses are divided in several manners, but the variations are of minor importance, the usual classification being along these lines:

1 *Power.* This includes the kilowatt-hours of energy plus any labor charges for battery charging. The average kilowatt-hour rate when the charging is done on off-peak hours is about 2 cents per kw-hr. A careful examination of the rate structure of the company supplying energy should be made to determine the net cost per kw-hr., as battery load may improve the load or power factor so that a general improvement is made in the users' rate. Separate metering for battery charging is in general preferable. The labor for charging varies with the type of equipment used and must be correlated with the fixed charges of the equipment. Approximate figures for this item run about 19 kw-hr. hours at 2 cents an hour or 35 cents per eight-hour day.

2 *Maintenance.* Maintenance is preferably divided into three subdivisions, namely, truck, battery, and charging equipment so that total costs on each item may be reached. Items generally included under this heading are oil, grease, distilled water, flushing battery, small parts, tire replacements, periodic inspection, and minor repairs. Major replacements or rebuilding should be charged against the reserve for depreciation as these latter will increase the life of the truck.

Using the averages for the different items above we arrive at the following summary of average yearly costs:

| | |
|---|---|
| Depreciation of truck | $300.00 |
| Depreciation of battery | 200.00 |
| Depreciation of charging equipment | 15.00 |
| Interest, insurance, and storage charges | 245.00 |
| Power | 225.00 |
| Maintenance and repairs | 225.00 |
| Total equipment cost | $1210.00 |

or $50^1/_2$ cents per hour on a basis of 300-eight-hour days per year.

It is seen that a large proportion of the cost lies in the fixed charges on the equipment. A graphical analysis has been made

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in Fig. 1 of the Appendix, in which chart these costs are compared with those of gasoline equipment whose fixed charges are smaller but operating expenses higher. This analysis gives the cost per number of hours in service per year.

Quantitative data on costs are not readily available, but the following actual cases have been chosen rather because it is believed that all direct costs have been included than for any comparison with other methods or savings effected.

Complete and accurate operating costs have been made available by a southern firm handling marine freight. The year's record for one truck and 3 men is as follows:

| Production | |
|---|---|
| Tons handled | 19866 |
| Man-hours | 7367 |
| Labor cost | $3502 |
| Tons per man-hour | 2.70 |
| Labor cost per ton | $0.176 |
| Equipment cost per ton | 0.063 |
| Total cost per ton | $0.239 |
| Saving per ton | $0.103 |

| Costs | | |
|---|---|---|
| Power | $379.10 | |
| Labor charging | 174.22 | |
| Flush, oil and grease | 82.03 | |
| Repair labor | 97.84 | |
| Repair material | 54.48 | |
| Total operating cost | | $787.67 |
| Truck depreciation | $150.00 | |
| Battery and charging equipment depreciation | 182.00 | |
| Interest on investment | 125.00 | |
| Total fixed charges | | 457.00 |
| Total equipment cost | | $1244.67 = 52 cents per hr. |

The power costs on this installation seem particularly high, but this implies the heavy use of the truck. The saving of $0.103 amounts to $2036 annually.

Power costs show extreme variations, and in contrast to the figures above are the costs of a truck operating in a steel plant where the power generated is a by-product of the main operation.

| | |
|---|---|
| Power | $ 36.00 |
| Labor and repairs | 300.00 |
| Truck depreciation | 180.00 |
| Battery and charging-equipment depreciation | 192.00 |
| Annual equipment cost | $708.00 |

A foundry operating 24 electric lift trucks found the average yearly cost per truck to be as follows:

| | |
|---|---|
| Truck depreciation | $135.00 |
| Battery depreciation | 97.00 |
| Charging-equipment depreciation | 15.00 |
| Interest on investment | 119.00 |
| Power at 1 cent per kilowatt-hour | 50.00 |
| Repair and maintenance—labor | 81.00 |
| Repair and maintenance—material | 138.00 |
| Oil and grease | 6.00 |
| Annual equipment cost | $641.00 |

A New England leather concern operates a fleet of electric trucks under severe conditions. Hauls are partly over city streets and partly over the slippery runways of various departments of the tannery. Occasionally trucks drop from runways to tanning vats, but without serious consequences other than necessity for a few hours drying out. Such conditions are reflected in the costs, but to a surprisingly small degree.

| | |
|---|---|
| Power | $183.00 |
| Labor for charging | 75.00 |
| Repair and maintenance material | 459.00 |
| Repair and maintenance—labor | 186.00 |
| Overhead on investment | 597.00 |
| Annual equipment cost | $1500.00 |

A large automobile concern present their costs in a form slightly different from that used above, but it presents an excellent example of those indirect savings which this company has been able to evaluate. These costs show a comparison between old method of handling sheet steel and the use of a 10-ton lift truck which was developed by the company for handling sheets in bundles of that weight.

The figures:

| | Cost per ton: Old method | Cost per ton: New method | Saving by new method |
|---|---|---|---|
| Damage to sheets chargeable to steel mill | $1.035 | $0.261 | $0.774 |
| Damage to sheets chargeable to railroad | 2.688 | 0.066 | 2.622 |
| Labor at steel mill, finishing to cars | 0.19 | 0.08 | 0.110 |
| Labor at receiving plant, cars to storage | 0.38 | 0.03 | 0.35 |
| Cost of bracing, including return freight on bracing materials by new method | 0.325 | 0.31 | 0.015 |
| Maintenance and depreciation, plant equipment of steel mill | 0.05 | 0.04 | 0.01 |
| Maintenance and depreciation, plant equipment of receiving plant | 0.04 | 0.03 | 0.01 |
| Freight-car damage | 0.416 | 0.00 | 0.416 |
| | $5.124 | $0.817 | $4.307 |

All direct costs are influenced by operating conditions. Figs. 2, 3, 6, and 7 of the Appendix contain theoretical curves showing the effect on the operating costs of different types of trucks resulting from variations in:

1 Length of haul
2 Amount of material to be handled
3 Condition of runways
4 Number and severity of ramps.

In addition to the above, the following conditions have a decided effect on the cost of operation. However, this case does not admit of any analytical treatment. Experience will have to be used in determining their influence in the choice of any type of equipment:

5 Width of runways and available space
6 Fragility of material handled
7 Special requirements in handling
8 Labor market conditions
9 Range of uses for which equipment is employed.

All or any one of the above factors may govern the selection of the most economical equipment but it is the authors' thought that the chances for a correct solution to the problem will be increased by a separate consideration of the component elements.

Geo. F. Swain, past-president of the A.S.C.E., has often been quoted as saying that a most common fault of the engineer is the carrying out of computations to a greater degree of accuracy than was warranted by the data from which these computations were made. Nowhere is this statement more applicable than in the field under our consideration, as the deciding factors in the purchase of materials-handling equipment are often those impossible to evaluate in dollars and cents. Such a statement should not be interpreted as implying that accurate cost figures are not valuable. They are, and when supplemented by a thorough investigation into all indirect savings, they form the only proper basis on which to make the final decision in questions of this kind.

Indirect savings effected by the introduction of a new system of handling or the purchase of new equipment are most readily taken care of by considering them as an indirect cost of the old system. If interest charges on the system under consideration be included in the cost and all savings are charged as costs of the system where they are *not* realized, the difference between total costs will then be the net yearly profit accruing from the change. If interest charges are omitted the difference in costs represent the annual savings which are available to meet the interest charges on the new system. An outline for computations of this kind is included in the Appendix.

Although difficult to evaluate, the following savings should be

considered so far as possible in figuring the net cost of operation of the electric industrial truck:

Fixed Charges:

1 Decrease in interest charges on manufacturing and storage facilities
2 Decrease in interest charges on inventories
3 Decrease in insurance charges on the two items above
4 Adaptability of system to growth in capacity.

Operating Charges:

5 Decrease in labor burden and managerial overhead
6 Decrease in idle hours of machines and workers
7 Decrease in charges for goods broken in process
8 Decrease in hazards to workmen
9 Decrease in expenditures due to labor turnover
10 Increase in general morale.

Offsetting these indirect savings we have the following indirect costs:

1 Interest on plant changes necessary[2]
2 Lost production during changes.

Decreases of insurance, goods broken in process, and hazards to workmen, as well as capacity for expansion, refer particularly to the installation of electric industrial trucks and tractors, the balance being applicable to mechanical systems regardless of type.

In summarizing the contents of the paper we find:

1 That in an effort to lower the cost of production, the mechanical handling of materials is coming into more and more prominence, but that variation of conditions makes comparative cost accounting difficult.
2 That a fairly simple classification of direct costs is possible.
3 That in average installations the electric truck costs in the neighborhood of 50 cents per hour to operate.
4 That in specific installations there is a considerable variation of cost.
5 That the influence of operating conditions is capable of being analyzed.
6 That indirect savings or costs are always present though difficult of valuation.

# Appendix

## THE COES FORMULA

As a typical example of a method of figuring investment justified or savings from operation we wish to refer here to the formula of H. V. Coes presented to the Society in November, 1923.

Let:

Debit Items:

$A$ = percentage allowance on investment
$B$ = percentage allowance to provide for insurance, taxes, etc.
$C$ = percentage allowance to provide for upkeep
$D$ = percentage allowance to provide for depreciation and obsolescence
$E$ = yearly cost of power, supplies, and other items which are consumed, total in dollars

Credit Items:

$S$ = yearly saving in direct cost of labor in dollars
$T$ = yearly saving in fixed charges, operating charges or burden, in dollars
$U$ = yearly saving or earning through increased production, in dollars

Results:

$X$ = percentage of year during which equipment will be employed
$I$ = initial cost of mechanical equipment
$Z$ = maximum investment in dollars justified by the above consideration
$Y$ = yearly cost to main mechanical equipment ready for operation
$V$ = yearly profit from operation of mechanical equipment.

Then

$$Z = \frac{(S + T + U - E)X}{A + B + C + D} \quad [1]$$

$$Y = I(A + B + C + D) \quad [2]$$

and

$$V = [(S + T + U - E)X] - Y \quad [3]$$

Feeling that handling machinery, even if left idle a large part of the year, would probably require, under most conditions, approximately the same repair through deterioration as though in use, the Committee makes no deduction for such lack of use in the estimated cost of upkeep $C$. If greater accuracy be considered necessary, use $C$ multiplied by $X$ in place of $C$ in the formulas.

In addition to the above items two other items may be considered. First, the interest earned on the depreciation reserve, which at 6 per cent is equal to 3 per cent on the value of the investment. This may be subtracted from item $A$ or $D$, the net being $A'$ or $D'$.

The second item is the interest on investments made in plant changes necessary before utilizing the mechanical equipment. This might be added as follows:

$F$ = yearly interest charges on cost of necessary changes to plant
$F = 0.06G$ ($G$ being the investment in plant changes)

This factor is added to the formula as it may play such an important part in the ultimate savings. One case is known where an investment of $1,500,000 was made in runways, bridges between buildings, etc.

Thus formulas [1], [2], and [3] above may be elaborated as follows:

$$Z = \frac{(S + T + U - E)X}{A' + B + CX + D} - G$$

$$Y = I(A' + B + C + D)$$

$$V = [(S + T + U - E)X] - (Y + F)$$

## HOURS OF USE VS. COST

The amount of time a piece of equipment is in service has a distinct influence on the cost of operation but not as great as many imagine. Many plant managers say that the high initial cost of electric trucks or tractors prohibits their use because the equipment would not be of service more than a few hours per day. Supposing a case where a gasoline or electric truck will replace 4 men at $3.50 per day and assuming (which is seldom true) that the men can be employed productively when not handling material we can draw the three curves shown in Fig. 1 of cost vs. days per year or hours per day employed.

## EFFECT OF VARIOUS FACTORS ON OPERATING COSTS

The following curves are presented not as accurate results of tests made nor are they true graphical representations of the formulas which follow them. They are presented as a suggested method of approach to the problem of selecting the most economical equipment operating under given conditions.

### Cost vs. Length of Haul

The first condition to be considered is the length of haul. Letting $Y$ = operating cost and $X$ = length of haul, and assuming that the cost is influenced by this one condition only, the following formula is suggested:

$$Y = A + \frac{B}{X} + C\frac{X}{r}$$

The authors have included three terms in the cost formula:

1 The fixed charges represented by $A$.

2 The cost of the equipment when idling, being a constant $B$ which represents the hourly cost of the truck when stopping for short periods, times the time idle which is inversely proportional to the length of haul. The second term may then be represented as $B/X$. For hand or electric trucks $B = 0$.

3 The third term is the cost of the machine when moving. This

[2] In one instance an expenditure of $1,500,000 for this item was found to be justifiable.

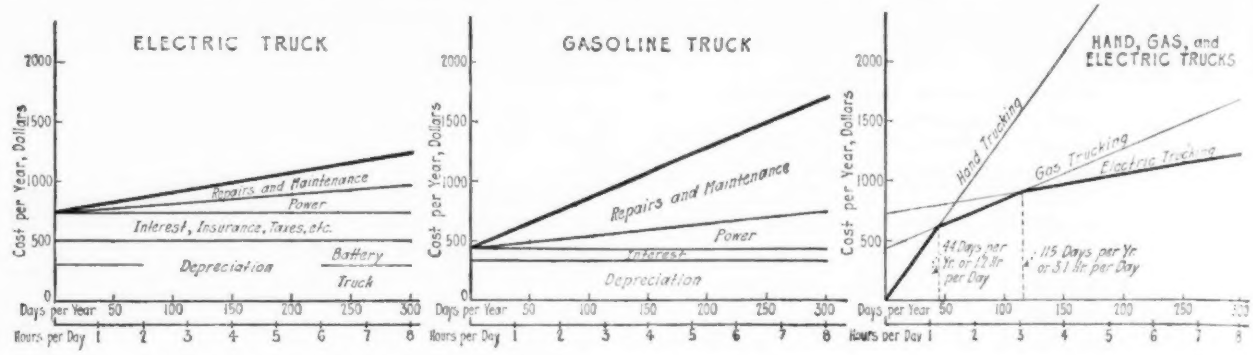


FIG. 1 OPERATING COSTS VS. HOURS IN SERVICE

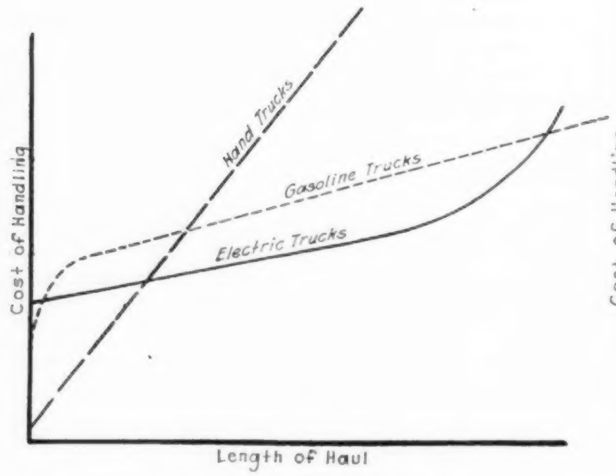


FIG. 2 COST VS. LENGTH OF HAUL

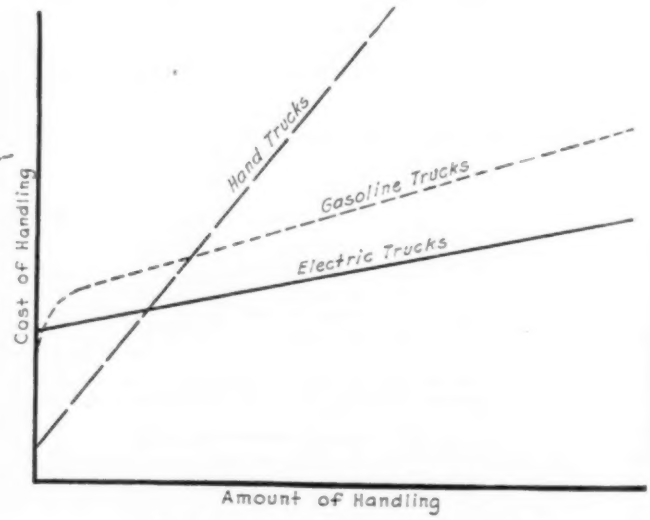


FIG. 3 COST VS. AMOUNT OF MATERIAL

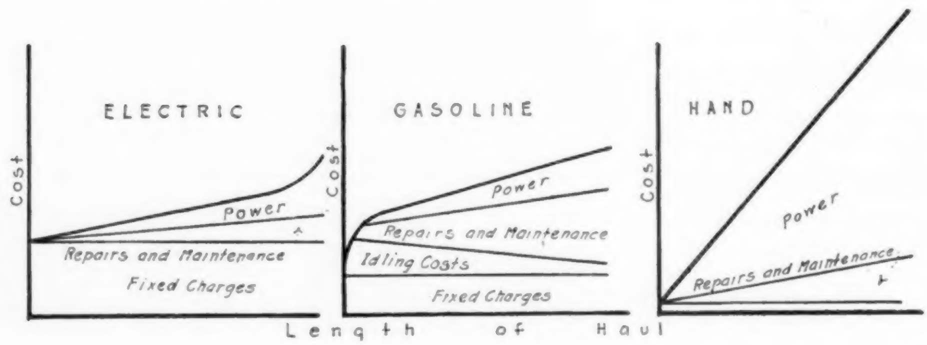


FIG. 4 ELEMENTS OF COST VS. LENGTH OF HAUL

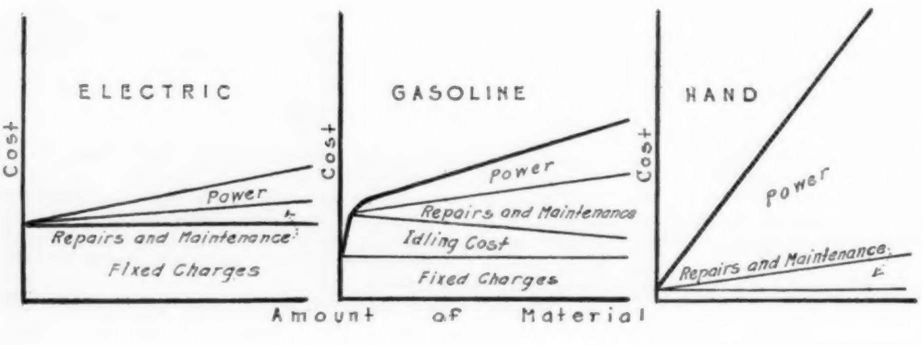


FIG. 5 ELEMENTS OF COST VS. AMOUNT OF MATERIAL

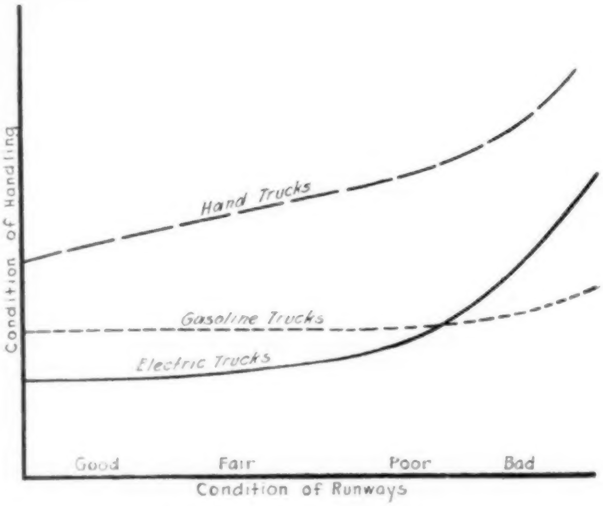


Fig. 6 Cost vs. Condition of Runways

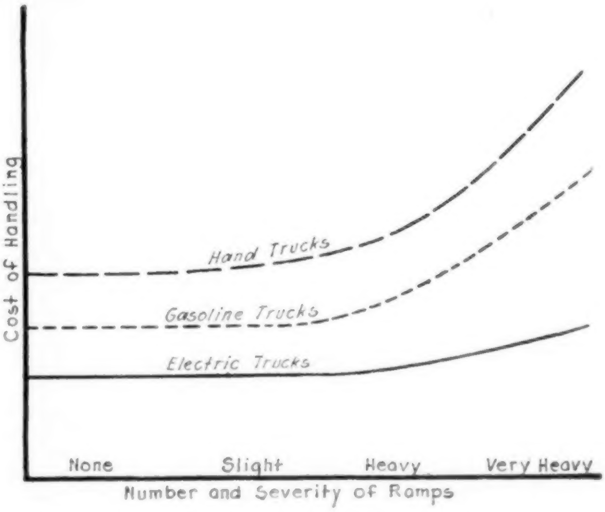


Fig. 7 Cost vs. Number and Severity of Ramps

term is a constant $C$ representing the cost per hour when running, corrected so that the variables remaining are only the length of haul $X$ and the speed of the truck $r$. The influence of speed is not seen in the cost until the hauls are of considerable cost.

The analysis of the different costs is shown in the curves of Fig. 4.

### Cost vs. Amount of Material

The second condition is the amount of material handled. The formula and curves are both similar to those for the length of haul.

The fixed charges are the same as before, the idling cost is proportional to the capacity of the truck and inversely proportional to the amount of material. The cost while running is proportional to the amount of material divided by the capacity of the truck. The formula is:

$$Y = A + B\frac{M}{X} + C\frac{X}{M}$$

where $B$ = idling constant
$M$ = capacity of truck
$X$ = amount of material.

The curves are shown in Figs. 3 and 5.

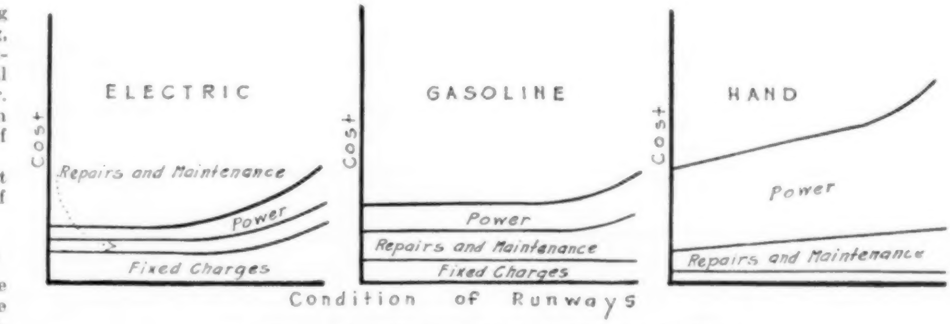


Fig. 8 Elements of Cost vs. Condition of Runways

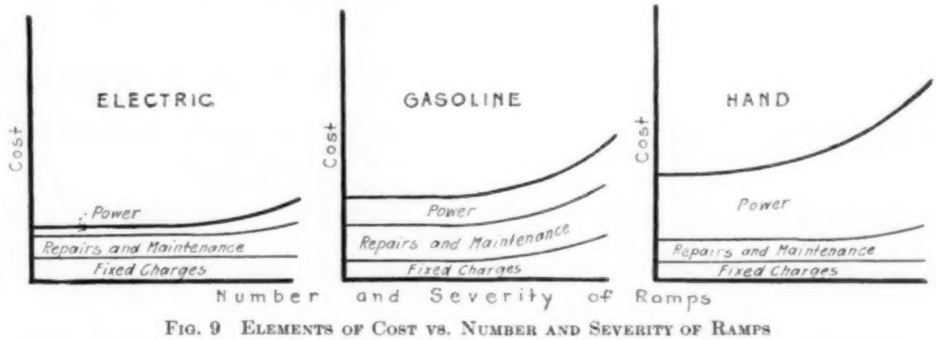


Fig. 9 Elements of Cost vs. Number and Severity of Ramps

### Cost vs. Condition of Runways

The third variable influencing cost is the condition of runways. The cost here is influenced by the amount of torque necessary at the hub and varies inversely with the size of the wheel. The electric has to retain the small wheel for the sake of ease in handling as the benefits therefrom generally exceed any trouble experienced on bad runways.

The curves are given in Figs. 6 and 8; the formula is as follows:

$$Y = A + B + C\frac{X}{DT}$$

where $D$ = diameter of wheel
$T$ = torque available
$B$ = constant for handling on smooth runways.
$X$ = coefficient for runway.

### Cost vs. Number and Severity of Ramps

The last external condition whose influence on cost is possible of any analysis is the number and severity of ramps. Considering as a base the fixed charges plus operating expenses on a level floor we may add a variable cost which is added by the ramps. This cost is principally one of power or more exactly one of overload capacity. As the storage battery has an overload capacity of 300 per cent or more the operating cost of electric trucks is little influenced by this item, being merely the extra power cost. In the case of gasoline or hand trucks, however, with a definite overload limit, either units of larger capacity (or smaller loads) or a sharp increase in maintenance and repairs and power will occur.

The curves are given in Figs. 7 and 9, and the formula is as follows:

$$Y = A + B\frac{X}{M}$$

where $A$ = fixed charges
$B$ = cost of operation on level runways
$M$ = capacity of truck for overload
$X$ = coefficient for number and severity of ramps.

SUMMARIZED DATA ON COSTS, SAV-

| No. | Industry | Plant | Operation | Working Conditions | Type Truck |
|---|---|---|---|---|---|
| 1 | Automobile | .................. | Millwright service | Narrow aisles, congested areas | 2-ton crane |
| 2 | Automobile | Reo Motor Car Co. | Carbonizing | Extreme heat, 2 shifts | Modified high lift with forks |
| 3 | Automobile | .................. | General handling | Generally smooth inside and outside | All types. Lift in capacities to 10 tons |
| 4 | Brick | Westfield Clay Products Co. | Handling from kilns to storage and shipping | Rough outside runways. Partly over ground | 2-ton standard elevating platform |
| 5 | Chemical Manufacture | Lehn & Fink Co. | Handling from cars to storage through process and to shipping | Smooth runways but heavy grades | 2-ton standard elevating platform |
| 6 | Electric Railway Repair Shop | Milwaukee Electric Railway and Light Co. | General machine-shop haulage | Concrete runways, small elevators | 2-ton standard high lift |
| 7 | Foundry | Erie Malleable Iron | Hauling sand, castings, molds, slag, etc. | Fair runways. Air filled with grit. Regular overloading | 2-ton standard low lift |
| 8 | Foundry | ....Mfg. Co. | Core handling | Concrete runways | Standard tractor |
| 9 | Iron and Steel | ....Can Co. | Tin-plate handling | Fair runways, varying grades | Special tin-plate jaw-clamp truck |
| 10 | Iron and Steel | Clinton Furnace | Charging blast furnace | Fair runways, 52 in. clearance for truck | 32-cu.-ft. side-dump built on straight platform truck |
| 11 | Iron and Steel | Detroit Steel Products Co. | Handling spring parts and springs through plant and to shipping | Fair runways. Grade 9 per cent, 34 ft. long to shipping level | Standard 3-ton elevating platform |
| 12 | Iron and Steel | Dilworth-Porter Co. | Handling tie plates from presses to shipping | Concrete floors | 4-wheel, 42-cell tractor |
| 13 | Iron and Steel | .................. | Handling crankshafts through forge plant | Fair runways but intense congestion grades. Hot loads | 3-ton elevating platform |
| 14 | Iron and Steel | .................. | Handling fender stock from machines through cooling to pickling and from finishing to shipping | Congested runways | 2-ton rated-capacity ram trucks |
| 15 | Iron and Steel | E. G. Budd Co. | Handling dies | Fair | High lift |
| 16 | Leather | .................. | Handling chemicals, hides, stretcher frames, etc. | Slippery wet runways. Narrow | Low-lift 2-ton standard |
| 17 | Paper | B. P. Co. | Handling rolls and flat stock | Concrete runways | 2-ton extra long platform, low lift |
| 18 | Paper | ....Lithograph Co. | Handling skid loads from cars to storage and to presses | Self-opening doors, concrete runways | 2-ton high-lift standard |
| 19 | Rubber | B. F. Goodrich Co. | Handling all materials throughout plant by skid and trailer loads | Underground tunnels, ramps, congested plant aisles | 2-ton high-lift trucks, standard tractors |
| 20 | Railroad and Marine | ....Terminal Co. | Handling freight from dock to car or warehouse | Rough—inside and outside | 2-ton high lift |

INGS, AND OPERATING CONDITIONS

| Auxiliaries | Hourly Operating Cost | Net Saving | Remarks |
|---|---|---|---|
| None | $0.45 | 30 men | This equipment is used for moving motors, machinery, etc. in order to take care of constantly shifting production layout. One in a fleet of 4 trucks. |
| Trestle for placing loads and chain hoist for dumping | | 6 men per shift | Approximately 50 per cent increase in effective furnace time has been obtained as the result of this innovation. Truck cares for 11 furnaces. |
| Skids | | $5 to $17 per car, net $4.83 | Skid shipment of materials to this plant from suppliers is beginning to be practiced. A further cut of 50 per cent is anticipated as a result of using higher capacity equipment. |
| 70 wooden skids per truck | | 6 men | This truck has solved the problem of labor in a district where it is scarce. It moves 35,000–40,000 brick a day in unit loads of 500 weighing about 2700 lb. |
| 100 wooden skids per truck. Hand lifts for short hauls | 0.53 | 19 men | Hand lift trucks are used for transfer of materials within departments, which cover relatively small areas. Roads are provided for practically all movements of the electrics. |
| 200 box skids per truck | | 5 men | Truck moves 100 loads in 8.6 hours. Many unusual jobs such as placing compressors under cars, handling stores in and out, etc. |
| Flat malleable skids: box skids and dump skids | | 4 men or more | Trucks are in some cases 12 years old. Minimum saving per unit cited. At this plant 4 pot-charging trucks handle 2500 tons daily at a total power cost of $4. |
| Special spring suspended trailer | | 62 man-hours per day | Breakage has been decreased and rehandling minimized. No difficulty experienced even in handling delicate cores. |
| Trailers for long hauls | 0.30 | $3.50 per car handled once | Impossible to cite net daily saving because load handled varies considerably. Equipment pronounced "eminently satisfactory." |
| 1 spare battery for each truck | | 4 men per shift | Trucks work 2 shifts. One truck handles 600 tons an average distance of 75 ft. every 24 hours. Better distribution in furnace claimed than by hand charging. |
| 250 all-steel skids for each truck | | 5 men per shift | One truck working on ramp and through plant, equipped with one spare battery, hauls 381 tons per day in 118 loads—an average load weight of 3.23 tons. Miles per day = 8.1. |
| 16 4-caster wheel 5-ton trailers | | 8 men per shift | At peak 665 tons are handled in 10 hours—a distance of from 50 to 150 ft. System is coordinated with overhead carrying equipment. Handling now involves no turnover. |
| All-steel skids | | 18 men per shift | Hot, heavy fast handling. Material in process kept on skids from time of shearing to shipment. 500 tons handled 5 to 10 times per day by 7 trucks. |
| None | | Cost earned once each month | Equipment has relieved congestion so severe that formerly periodic shutdowns of entire plant were unavoidable. Damage to product has been minimized. |
| None | | $112 per month | Saving is figured, by user, to include among other items the elimination of idle press time. Six-ton trucks are now used for this work in body-building plants. |
| Wooden skids | 0.60 | From 10 to 18 men | Equipment busy 8–12 hours a day. Hauls run to 1000 ft., outside. 2500–3000 lb. represents average load. Unusual reduction of labor turnover in sunning yard. |
| Wooden skids | 0.30 | 5 men | Materials are kept off floor throughout process. In some operations old hand trucks (4-wheel) carry loads which are pushed by power trucks. |
| Wooden skids 11 in. high | | 9 men | Power used nearly exclusively for moving material which is kept constantly off floor. Skid receipt of paper stock found to decrease unloading cost greatly. |
| None | Less than 0.40 | 6 men shift | Average load for truck = 1500 lb. Trailer load, 4500 lb. Average material moved daily by 47 lift trucks and 18 tractors between 9,000,000 and 9,500,000 tons. Average distance, 1787 ft. Total power charge on fleet per month amounts only to $175. |
| None | 0.43 | $6300 per year | Operation earning depends on length of time used. Operating cost verified by expert engineers. Saving cited a minimum. |

## Discussion

C. B. Cook.[3] The figures which the authors use appear to me to be quite conservative. In view of our experience, there seems to be an utter lack of records of costs in handling material by hand rather than machine. As a result we have nothing with which we can start. The costs which have been mentioned have been entered in overhead, whereas when one establishes a material-handling department it is usually put on its own basis, and these costs stand out as not before. It is therefore quite important that every encouragement be given industry to separate hand material-handling costs, first, to give them importance, second, for purposes of comparison with other means.

W. C. Brinton.[4] The paper brings out a thought I believe is important in the matter of large investments for the application of materials-handling machinery, such as electric trucks and tractors. Two or three years ago I asked for prices on the concrete paving of factory yards and was quoted a figure, roughly, of $10,000 per acre. One large foundry on a railroad system has about eight acres of yard where castings are stored, and for some three winters, electric lift trucks have gone over the whole area, which is nothing but cinder-fill. I believe it is usually possible to work in existing factory yards and between the buildings by using equipment that will suit the yards rather than spend $10,000 an acre for concreting them.

Take the subject of shipping. In the shipping of castor beans, for instance, one man by using a lift truck now saves the work of about twelve men. Heretofore the 150-lb. bags of beans were carried on the men's backs.

In handling brick at the New York City piers the brick must be stored near the pier. Lift trucks are doing this work, taking the brick about two city blocks away from the pier and putting it in a place under the open to be held until needed on the different construction jobs.

The accident-insurance rates have gone up recently to something like 12 or 15 per cent of the total paid to the longshoremen in loading and unloading ships. It is the duty of engineers to show the waterfront employers, superintendents, and managers how machine methods can reduce accidents.

Spencer Miller.[5] In handling material, it is the lift part that is difficult. Horizontal conveying is relatively simple. The great, successful industries that I knew forty years ago were those which had really solved their problems of material handling. One of the can factories of Chicago which later was a part of the American Can Co. made cans marvelously cheaply by improved apparatus, an essential part of which was the shop transportation system. The belt conveyor was a big factor in the making of the Duluth grain elevator, that great place for sorting wheat. And in the packing houses in Chicago the progress in material handling has been just as marvelous.

M. W. Potts.[6] With no other type of equipment than that for mechanical handling is it possible, when conditions change, to salvage so large an amount. A particular machine served by a lift truck may be taken out and yet one can find at least fifty per cent use for the lift truck with something else. This is also true of the conveyer. A year from now it may not be needed for the purpose it is now being used, but it can be put to some other use.

[3] Elwell-Parker Co., Cleveland, Ohio.

[4] Consulting Engineer, President and Treasurer, Terminal Engineering Co., New York, N. Y. Mem. A.S.M.E.

[5] Consulting Engineer, South Orange, N. J. Past Vice-President A.S.M.E.

[6] Flushing, L. I., N. Y. Assoc-Mem. A.S.M.E.

J. C. Gillette.[7] One point of saving with the electric truck mentioned in this paper has come up in our plant, namely, the night delivery of materials with the electric truck. Practically all materials are delivered in the basement. We use chutes, the discharge of which are kept off the ground high enough to unload on to the skid without lifting.

We use 3-by-5-ft. skid bins for such materials as rosin, paraffin, asphalt, etc. At night our electric trucks deliver these materials to the department where they are to be used during the day. This produces quite a marked saving on elevators, congestion in the aisleways, and the interference with the workers. An electric truck cannot pass through a five-foot aisleway, close to the backs of people working on each side without their slowing up. It can, however, at night.

The electric truck has proved very valuable to us in the placing of portable equipment, such as fans, blowers, etc. We also place the electricians', pipefitters', and millwrights' emergency equipment and supplies on skids, and in case of a breakdown they can be quickly taken to the work.

Mr. Potts remarked about the flexibility of conveyor systems. We have a beautiful example of this with the exception of a few curves. Every foot of conveyor equipment we had in use last spring has been moved, rebuilt, and put back in service.

H. V. Coes.[8] I was particularly interested in the paper, and should like to see the supporting data brought out. If it is to be of real use to industry, we need the fundamental information from which these graphs are derived. Some of us may arrive at different conclusions, but if the supporting information is available, some one may find ways and means of using it to even a greater extent than has been presented here.

C. H. Bigelow.[9] It is important that trucks be made heavy and strong enough to stand hard usage, for the class of men that use them are not as careful as they might be. Another question to be considered is the unit cost of power.

Max Sklovsky.[10] The company with which I am connected has in seven of its plants, truck and tractor equipment for materials-handling purposes. Three other plants of the company have no such equipment. As a result, in the seven plants so equipped, we have very little in the way of difficult materials-handling problems. Such difficulties are in those plants where we have no such adequate equipment. We find it is more difficult to operate a plant without tractor equipment than with it. One example will illustrate this. In one plant where we formerly employed about 60 men for materials-handling work, we have now reduced the force to about 18 or 20 men. It is much simpler to acquire and utilize apparatus than it is to place men for such a class of work.

In one of the equipped plants we have ten electric tractors and five gas tractors. A year's operation on these shows an average of $840 for the electric tractors and $560 for the gas tractors. These results do not agree with the curves shown in the paper. However, the gasoline tractors in this instance have been in service about one and one-half years, while the average age of the electrics is approximately eleven years. As a result, the maintenance is higher on the electrics than on the gas equipment, so that it would modify the margin previously indicated.

[7] Works Engineer, National Carbon Co., Cleveland, Ohio. Mem. A.S.M.E.

[8] Vice-President and General Manager, Belden Mfg. Co., Chicago, Ill. Vice-President A.S.M.E.

[9] Plant Engineer, Spicer Mfg. Corp., South Plainfield, N. J. Mem. A.S.M.E.

[10] Chief Engineer, Deere & Co., Moline, Ill. Mem. A.S.M.E.

The question of investment is one that can be looked at from different standpoints. As a result of using various types of handling equipment, we have been able to reduce lost time and delays so that the factory output has been increased accordingly within the same areas and with the same production equipment. The cost of handling equipment is therefore more than offset by the reduction in outlay for building areas and added production machinery which would otherwise be needed. A further advantage accruing in part to proper handling equipment is that of control of inventories. Delays in handling tend to increase the intermediate inventories; that is, process inventories. By a sufficient systematic handling plan it is possible to hold such inventories within a much smaller range than otherwise. Handling equipment on this account helps in the effort to control factory inventories, and in one instance, as a result of various endeavors including systematic handling of materials, the inventories were reduced to a 12-day supply, whereas previously a 45-day supply was carried.

C. B. Crockett. One discusser mentioned a percentage return on the investment and the materials-handling equipment having to pay for itself in a year or two years. That is a great obstacle to overcome. A central-station company will buy generating or substation apparatus if it can earn 6 per cent on the investment, but if one tries to sell materials-handling equipment to a central-station storekeeper, he expects it to pay for itself at the rate of fifty to one hundred per cent a year.

Mr. Bigelow remarked about the question of power for trucks. Generally electric-truck equipment is charged at night, during what is known as "off-peak" hours, and if anything, the use of electric handling equipment improves the plant load factor, and in that way would decrease the unit rate at which the power is charged.

Any comparison of cost has a great many features in it: The age of equipment: are you comparing old equipment with new equipment? Have both types of equipment been in service long enough to be on an equal basis? Are they doing exactly the same type of work? Are any costs such as injuries to the workmen or breakdowns being prorated between the two, or charged up to each type of equipment?

H. J. Payne. I think that Mr. Coes has raised the question that is uppermost in all of your minds, namely, what right had we to take such liberties with these formulas. But, in connection with the work we have done, we say (the paper probably should have italicized it): "The following curves are presented not as accurate results of tests made nor are they true graphical representations of the formulas which follow them. They are presented as a suggested method of approach to the problem of selecting the most economical equipment operating under given conditions."

Mr. Crockett and I recognized that one of the greatest questions today in the use of materials-handling equipment is that of the power to put behind a motor truck. We have made studies covering two hundred plants. About twenty-five different types of gasoline and electric trucks are being used. There is something lacking in our data in the case of every study we have made. We have attempted to get all the facts available, and I think in a great many cases we have, but all the facts put together did not seem to us to justify making a curve and saying that it was the last word on the subject.

However, we do feel we have isolated four factors that underlie that proper choice of power to be used. As to Mr. Sklovsky's question in connection with these curves, Fig. 2 shows the cost vs. length of haul. Here we are forgetting there is anything to consider except the distance over which to move the material. We show that the hand-truck cost goes up rapidly. That is largely labor. The gasoline-truck curve starts to rise rapidly and then runs along at a uniform, moderate slope. The reason for that first curve is the fact that on very short hauls the gasoline equipment loses much time in starting, and on short hauls it spends a large proportion of the day in idling. On longer hauls there are not so many stops. Therefore, for the reason of very short hauls, the curve suggested for gasoline equipment rises rapidly.

With the electric truck, we show at the start a cost much higher than for the hand truck, because we are carrying higher fixed charges there, and then at a distance not defined but which we believe is in the neighborhood of 1000 ft. in many cases, the curve rises very rapidly, and later it is entirely out of proportion with the gasoline curve. I would assume that the reason for Mr. Sklovsky's views on both types of equipment is that he has found for certain types of work certain of these factors are important, and more or less force the use of one type of equipment.

# Materials Handling as an Aid to Production

By FRANK L. EIDMANN,[1] PRINCETON, N. J.

*The author surveys the materials-handling problem of a plant from eight angles: the design of building and arrangement of equipment, the weight of material handled per pound of finished product, the elimination of hand labor, the effect of the materials-handling methods on inventory, the effect on increased output of the worker, the design of the product to facilitate handling, the selection of the handling equipment, and attempts to facilitate handling in shipment and in customer's plant. Examples of good and bad practice are quoted, and illustrations of some are included.*

MATERIALS handling in the plant may be considered from many different angles, and it is safe to say that from whatever angle this problem is considered it stands out as one of the most important factors in influencing the costs of production and distribution.

With the ever-narrowing margin of profit in manufacturing, careful study is made of all the possible ways of reducing costs. It is natural that first attention is given to improvement of manufacturing processes and methods. As a result, development in these directions has reached a stage where it is now generally difficult to produce further spectacular savings, hence a broader analysis of all the factors which relate to production must be made in order to find other possibilities for reductions in costs. Savings in the cost of materials have received their share of attention, notably the salvaging of by-products and former wastes. Remaining for investigation, then, are those elements of cost which are usually classed as manufacturing overhead, and in segregating these it is found that the cost of handling the materials and tools in the plant is of greater importance than has been realized by the majority of executives. It has been truly stated that materials handling forms a large part of the so-called "hidden" costs of production, for there are very few firms which segregate and keep an accurate record of their handling costs.

In making a careful analysis of the materials-handling problem of a plant with the idea of attempting to make improvements, the chief motive is, of course, the ultimate reduction of the manufacturing costs. There are, however, a number of angles from which the survey can be made so as to bring out the possibilities:

1 From the viewpoint of the influence of the materials-handling problem on the design of the building and on the arrangement of the production equipment.

2 From the viewpoint of the total weight of material and equipment that must be handled to produce each pound of finished product.

3 The elimination of hand labor so far as possible.

4 The influence of the existing and the proposed methods of handling on the inventory, which includes a study of the methods which will make it possible to keep the material moving, so as to obviate the material's standing idle for lengthy periods between the various production operations.

5 To increase the output of each worker by delivering the material to him as fast as he can use it, and also to increase the size of the loads where consistent.

6 A study of the product from the viewpoint of designing it to facilitate its handling.

7 The selection of the proper handling equipment:

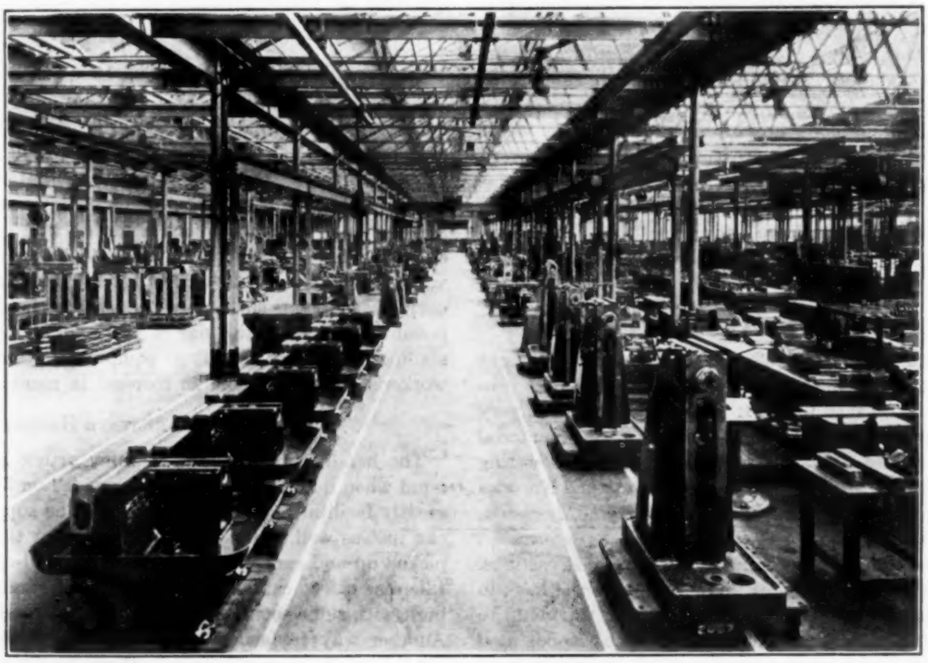

Fig. 1 The Cincinnati Milling Machine Company Handles Its Castings on Lift-Truck Skids from the Time They Are Received Until They Are Shipped as Completed Machines. The Assembly Floor Is Shown in This Photograph

[1] School of Engineering, Princeton University. Mem. A.S.M.E.

Contributed by the Materials Handling Division and presented at the Annual Meeting, New York, N. Y., Dec. 5 to 8, 1927, of The American Society of Mechanical Engineers.

*a* To provide economical handling of material from one place to another

*b* To provide safety for the operator of the equipment, as well as for other workers of the plant.

*c* To facilitate coordination of the handling equipment with the production equipment of the plant as well as with the handling methods in the other departments of the plant.

8 To facilitate shipment of the finished product to distant customers, and to facilitate handling in the customer's plant.

### Influence on Design of Plant

Referring to the influence of materials handling on the design of the plant building, it is interesting to note the change in procedure which has taken place in starting a new plant. Not many years ago, when a new plant was started it was customary first to construct the building, and after its completion the machinery was arranged to fit the structure. Later it became common practice to make a careful study of the desired machine arrangement before building the plant, and then to build the structure around this predetermined layout of equipment. The present method, however, is first to study the materials-handling problems, then to plan the proposed arrangement of equipment, and finally to design and construct the building to meet the requirements of both. This change is indicative of the growing recognition of the important part which materials handling plays as a factor in production.

Materials-handling methods are often an important factor in conserving floor space. There are many instances on record where the erection of new buildings has been rendered unnecessary through the adoption of improved methods of handling and storing materials. In a large gas-engine plant, after progressive assembly and a conveyor system were introduced, only about one-third of the floor space in the plant was required.

### Weight of Material

The second angle of investigation deals with the total weight of material and tools that has to be handled in the plant to produce each pound of finished product. This total weight is very high, and any improved methods of manufacturing or of material handling which reduce this will naturally result in lowering the cost of the product. In the foundry of the Blake and Knowles Works of the Worthington Pump and Machinery Corporation, for example, a careful analysis was made, and it was determined that 152 tons have to be handled for every ton of brass castings. For making one ton of iron castings, 206 tons of material have to be handled. These figures include the handling of the metal to and from the melting furnace, all handling of the materials used in core making, handling of sand equipment in molding, handling in the processes of cleaning and snagging, and delivery to the shipping room. Likewise, in the machine shop, or in any other plant, it is apparent that the total weight of materials and equipment that must be carried and lifted in order to produce a pound of finished goods also reaches a surprisingly high figure. A casting to be fabricated in the machine shop, for instance, has to be unloaded from the freight car or motor truck into the receiving room; usually it has to be lifted to be inspected; it has to be moved to the stock room or place of temporary storage; it has to be drawn from stock and then moved from machine to machine, from one operation to the next; it has to be lifted in and out of the machines; it has to be handled in the assembly and painting, testing, and preparation for shipment of the finished machine in which it is used; and finally it has to be loaded on the freight car. But that is not all, for many tools and pieces of equipment have to be handled, as well as quantities of supplies, to produce the part.

Naturally, the simplest way of cutting down the cost of materials handling is to eliminate manual handling as far as possible. If time studies are made in connection with making the investigation of the weight of materials that has to be handled to produce a single pound of product, one is again impressed with the shortness of the actual fabricating operations as compared with the total time involved. Some such time studies are reported which show as low as 10 to 15 per cent of the total time used in actual fabrication. The other 85 to 90 per cent of the time is used in handling the part, as well as tools, equipment, and supplies which are to be used on the part.

An analysis of time studies of this kind will sometimes suggest the elimination of some of the handling, and may further lead to the adoption of electrical or mechanical means of replacing manual handling.

### Influence on Inventory

Another angle from which materials handling affects costs is in its influence on the inventory of stock in process. If the material can be kept moving, without delays, from operation to operation, it is possible to run the plant on a much smaller inventory, which results in a reduction of invested capital and increases the yearly profits on account of the increased turnover of the materials.

### Delivering Material to Worker

The fifth study—to increase the output of each worker by delivering the material to him at the rate at which he can use it—goes hand in hand with the fourth, which has just been considered. In many plants there has been a substantial increase in the output as a result of the elimination of the waiting for materials. Where the product is of such a nature that conveyors may be employed for delivery of the material to the worker, the conveyor serves as a pace setter and usually shows an increase in the output. In plants such as dyeing establishments it is sometimes possible to increase the size of the loads to be handled by installing improved handling equipment, thus increasing the worker's output without an increase in manual effort required.

### Design to Facilitate Handling

The handling of a heavy or bulky article should be kept in mind when it is designed. Lugs provided on heavy castings will greatly facilitate handling by crane. The supports of machines can just as well as not be designed so that the machine can be picked up and carried by an electric or hand-operated lift truck. Likewise safes, cabinets, and articles of similar nature can be built with sufficient floor clearance to accommodate a lift truck. Another way to facilitate the handling of boxes, barrels, and other loads is to secure feet to them, to allow the proper floor clearance for the entrance of a lift truck. In similar manner the part may be designed to be handled by other types of equipment, greatly reducing the labor required.

### Selection of Handling Equipment

The selection of handling equipment is too far-reaching in its effects to be done haphazardly. It is not always a simple matter to decide which type of equipment is best suited to a handling problem, because sometimes it would appear as if any one of several types would serve equally well, whereas a thorough analysis of all the influencing factors by an expert who is not partial to any single class of equipment will usually show that one of the several available types will have definite advantages over the others for the particular problems at hand. Each type of handling equipment will be found to possess certain advantages for certain conditions, and there is no single type that will serve as a panacea for all handling problems—notwithstanding the ex-

tensive advertisements of some manufacturers of handling equipment. As previously stated, it is best to have the final selection of handling equipment made by an expert who is not partial to a single type of equipment. Some plants place such a man in charge of all materials handling, and in some of the larger plants the materials-handling department is well organized and the equipment is scheduled to jobs on a time-study basis and the operators are paid on a piece-rate or bonus basis. Smaller plants may not be able to afford the services of a materials-handling specialist. In that case it is suggested that a consulting specialist be called in occasionally to make a thorough and impartial analysis of the existing handling methods and to make suggestions. In most plants wasteful handling conditions are allowed to exist because it is no particular person's duty to correct them, and often those who know better allow such conditions to continue simply because they have existed for a long time and no especial thought has been given them. Not long ago the author visited the foundry of a well-known manufacturer and was surprised to find that whenever a mold had to be lifted or a core placed in a mold, the molder had to call four or five other molders from their work to help him. A hand-operated crane or a couple of jib cranes provided with chain hoists would have paid well for themselves. In another plant seven men were observed lifting heavy beams to the ceiling and holding them in place while other men secured them. If there were a materials-handling specialist in the plant he would undoubtedly have made use of the portable elevator, which was standing idle in the next department. One man, with the elevator, could have taken the place of the seven men referred to. In a third plant, which incidentally produces labor-saving machinery, about seven men were required to move the completed machines to the shipping room—and it was a long and laborious struggle. With hand lift trucks that were available in the same department of the plant, the machines could have been moved by two men in a fraction of the time, as is done in other plants of a similar nature.

One of the most essential requirements for a handling system is that it provides economical handling from one place to another. Sometimes, however, this requirement is secondary to other considerations. For instance, in one of the large tire factories at Akron it developed that the reason for installing a very extensive system of conveyors was not so that the handling from one place to another might be accomplished at lowest cost by this method, but because of the fact that work could be performed on the product while it was being moved. It was stated, in fact, that there were other available methods which would do the handling at lower cost.

### Safety

More important even than the consideration of handling cost is the provision of safety to the operator of the equipment and to the other workers of the plant. In general, any equipment which reduces the manual handling will greatly decrease the number of accidents. In this connection it is suggested that more firms establish the policy of providing critical inspection of all handling equipment and its use, from the viewpoint of safety. Insurance records show that a large percentage of injuries is due to falling objects—very often material falling from handling equipment. The Gleason Works and other firms find that it pays to place the responsibility for this inspection on a capable engineer. Special study is made of the proper way to arrange loads of material on the various types of equipment so as to eliminate the likelihood of accident. In the selection of equipment it is also well to look for attachments which make the equipment "foolproof." Consider, for instance, the electric industrial truck. It is now general practice to interconnect the brake and controller so that the danger of accident is greatly reduced. In order to operate the controller, the operator must hold the brake pedal in a depressed position against the action of a spring. Suppose the truck is running along at full speed and the operator for some reason becomes frightened, and jumps off the truck. The brake will automatically be thrown into action and simultaneously the electrical contact in the controller will be broken. Suppose the operator now returns to the truck and depresses the brake pedal while the controller handle is still in the running

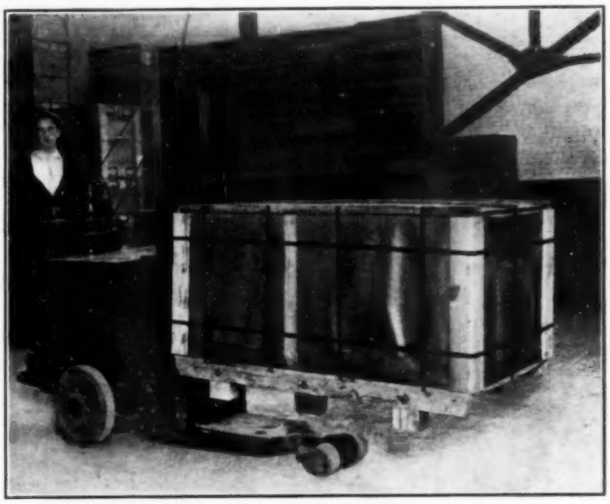

Fig. 2 The Practice of Shipping Product Loaded on Skids Is Rapidly Increasing. The Special Skid Illustrated Is One Which Has Been Developed by the Champion Coated Paper Company

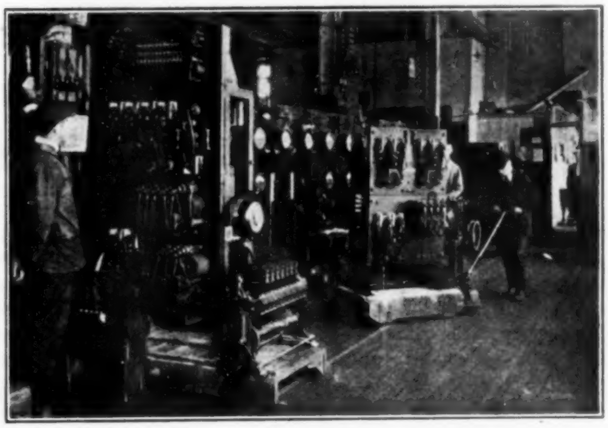

Fig. 3 At the Otis Elevator Company's Plant, the Control Boards Are Assembled and Handled Through the Test and Inspection While Secured to Lift-Truck Skids, Saving Considerable Manual Handling

position. The truck will not start. The controller handle must be returned to the neutral position before electrical contact will be made, and the machine has to pass through first and second speeds before it can be thrown into third.

### Coordination and Flexibility

Another point to consider in selecting handling equipment is the possibility of coordinating it with the other handling equipment of the plant as well as with the production equipment. There are plants where different types of handling equipment are employed in the various departments, with the result that there is considerable waste of labor in transferring the loads from one

department to another. Most types of handling equipment can be coordinated to use with other types. Usually some way can be devised of handling the same load by the different types of equipment without involving any manual handling in making the transfer. Flexibility is sometimes an important point to consider in selecting handling equipment—flexibility from the viewpoint of being able to employ the equipment in all parts of the plant, under low ceilings and balconies, on and off elevators, and in congested aisles. As previously stated, there are many

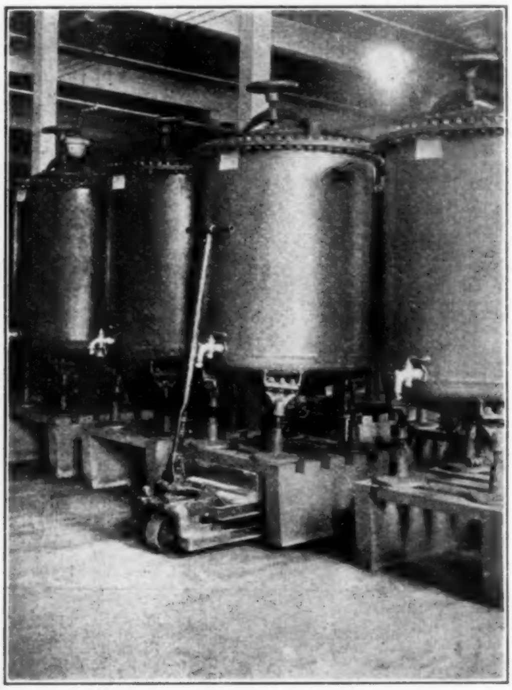

Fig. 4 The Handling of Heavy Loads May Be Greatly Simplified by Securing a Set of Feet or a Special Skid Thereto. This Photograph Shows How the United Drug Company Handled Its Heavy Vats of Perfumes

things to consider in making a selection, there being hardly any two installations which face exactly the same problems. Even the matter of fire-insurance rates is influenced by materials-handling methods. In a number of instances insurance rates have been lowered upon the introduction of the lift-truck and skid method of handling. The explanation for the rate reduction lies in the fact that this system allows for rapid removal of the stored product, thus decreasing the damage resulting from the operation of fire sprinklers. Also, the loads being at skid height above the floor, the liability of damage from the wet floors is reduced.

### Return on Investment

One of the important questions which is asked when the purchase of handling equipment is proposed, is, "How long will it require to pay for itself?" There is considerable divergence of policy among firms as to the answer to this question. Some firms require that the period be less than a year; others fix it at two years; while some are satisfied if the annual savings in production costs which result from the purchase can be shown to be greater than the annual charges against the equipment. One large company makes it a rule to require the new equipment to pay for itself, in labor saving alone, within a year. There may be additional large savings which result from the use of the equipment—such as in floor space, cutting down inventory, reduction of accidents, reduction of breakage of materials, and increased production—but the savings in labor alone has to pay for the equipment in the allotted time. Few firms keep accurate cost records of their materials handling, and it is therefore usually impossible to say exactly what savings have been accomplished through the adoption of a new piece of handling equipment, other than to state that the labor item has been reduced by a certain amount. Spectacular savings have resulted from the installation of each of the many types of handling equipment. In some plants new conveyor installations have returned annually as high as 100 per cent on the investment. In other plants the wages of a man were saved for each air hoist introduced in a particular department. Reports on many electric-truck installations show a saving of the wages of from three to five men for each truck employed. There are other reports of large savings resulting from the use of portable elevators—in one instance a saving of $2200 a day. Reports from many users of hand lift trucks indicate that each truck saves the wages of one man—about $1300 a year—not including the other savings mentioned in this paper.

### Shipping Methods

The last of the viewpoints from which the subject is considered is that of coordination of handling in the plant to the shipping methods. An example is the rapidly growing practice of shipping goods to distant plant on lift-truck skids. This method of shipping was first tried by the pulp manufacturers. The pulp was loaded into freight cars on lift-truck skids, saving considerable labor in loading the car and also in unloading and handling the pulp at the paper mills. This met with such success that the idea has been applied to the shipment of sheet paper—principally coated paper. The load is securely strapped to wooden skids, otherwise there would be likelihood of the paper sliding off the skid during transit. Some firms make up inexpensive wooden skids which are not returned to the shipper. Other plants are experimenting with a more permanent skid of which the cost warrants return for further use. This method of shipping has been extended to the shipment of sheet metal, which is loaded and strapped on skids similarly to paper. Products such as electric control boards and machinery are also being shipped on skids, and it is expected that this method will be extensively used within a few years, accomplishing enormous saving in time and labor of loading as well as a reduction of breakage. Some firms are now specifying that shipments come to them packed this way, and go so far as to send to shippers a set of printed instructions as to how to arrange the loaded skids in the freight cars so as to facilitate unloading, and also as to the dimensions of the skids to be used.

The importance of materials handling as a factor in production is unquestionably realized by management today, and considerable attention is being given to the improvement of existing conditions and methods; but only a beginning has really been made, and large opportunities for big reductions in costs still lie latent in this direction.

## Discussion

G. E. Hagemann.[2] Progress is rapid at present in the materials-handling field. The engineer is essentially the man who has the facts within his control and who is going to say how far this progress in materials handling shall continue? He is the only man who can keep in touch with new developments in equipment. It therefore devolves upon the Materials Handling Division more than on any other group to support the progress in that line of work and cut down the three billions or more of loss

[2] Associate Editor, *Manufacturing Industries*, New York, N. Y. Mem. A.S.M.E.

that industry is suffering annually because of inadequate and antiquated methods of handling material.

Materials handling today is far in advance of what it was ten years ago, and in the next ten years we shall certainty see a far more remarkable development. However, many plants will never buy handling equipment until the idea has been "sold" to them.

A small plant stands as much chance to save as the big one worth one hundred million dollars. We must remember, however, that we not only have to install the correct equipment, but also we have to make sure that we get the full use of it when it goes in. Further, a good deal of psychology must be employed in materials handling to get the workmen and supervisors to use the equipment properly. They can hardly be expected to do so all by themselves.

The Materials Handling Division of the Society has probably the biggest opportunity of any division for growth and development at the present time. We can point out how to save millions and millions of dollars a year that are now wasted in industry. The engineer should be a good lawyer to argue his case, a good salesman to sell the idea to the plant manager, a good economist to measure facts rightly, and a good cost accountant to state the financial facts logically and convincingly. If he can do this, there is no end to the amount of money that can be saved.

There is no plant in the country today that cannot next year reap anywhere from a ten to one hundred per cent bigger return on its investment in handling equipment through restudying its problems and bringing its methods and equipment up to date.

A. L. Lewis.[3] Because the writer is a manufacturer of lift trucks, stackers, platforms for lift trucks, barrel racks, and special designs of caster trucks, he believes his most worth-while contribution to the discussion will be to tell of concrete cases in ten major groups of industry where his concern's products have been installed and the savings effected.

1 *Chemicals, Paint, Varnish, Etc.* Company uses a lift truck for handling tote boxes 36 in. high and 36 in. wide which are inserted under a hopper and filled with a finely powdered chemical. The hydraulic-jack mechanism of the lift truck in question is such that the truck frame can be elevated and yet stopped at the right height to make the top of the tote box and the bottom of the hopper a pressed fit, which is necessary to prevent the material from filling the air.

2 *Food Products.* A branch of a well-known packing house uses lift trucks for handling crates of eggs. One man trucks from the freight car to the elevator and another on the lower floor from the elevator to storage. The time now is 40 working minutes. The previous time was 240 working minutes. When unloading cars of produce, two men pile it on platforms and another with the lift truck hauls it into the plant. Another concern stacks barrels of fruit three high in its cold-storage room, and the saving in floor space and labor thus effected more than paid for the stacker used in a very short time.

3 *Iron and Steel Products.* One concern uses hand lift trucks on each floor to take loaded platforms off the elevator. Later these loads are distributed where required by electric lift trucks. This method has increased the tonnage handled by the electric lift trucks very considerably, and is illustrative of how an inexpensive unit like a hand lift truck can increase the earning power of an expensive unit like the electric lift truck.

Another concern, which originally bought a stacker for piling filled boxes of rivets in storage, wrote that the machine had practically paid for itself during the equipment of its new building, because of the labor it had saved in hanging motors and shafting.

4 *Leather Products.* About a thousand hides can be stored on a platform, whereas not over 200 can be stored on the wooden horse that it has been the custom to use. The saving in floor space is consequently considerable, and one company states that the saving made by using three hand lifts amounts to over $10,000 a year.

5 *Lumber.* One concern unloads veneered panels used in the manufacture of kitchen cabinets by placing a wooden platform at the freight-car door and piling panels upon it. The platform is then raised off the car floor by a stacker and hauled away to the storehouse. Two men less are required on the job.

A manufacturer of casters uses hand lift trucks to handle the lignum-vitae, of which the casters are made, and which comes to them in four-foot logs, about 6 in. in diameter. Rack platforms were built and the logs are dropped from the railroad car to the racks. The wood is so heavy that a 4-ft-high load is all a man can haul. The trucks handle these racks and make a one-man job of what formerly was accomplished with difficulty by two men.

6 *Paper and Printing.* A large metropolitan newspaper is using hand lift trucks in the color-press department where the magazines and comic sections are printed. These sections are printed about a week in advance, and as they come off the presses are tied in bundles and placed on platforms 32 in. wide by 36 in. long where they are stored until made a part of the regular editions. The trucks and platforms save at least two handlings and materially speed the deliveries.

A paper mill uses a stacker for piling rolls of paper and boxes of paper to a height of 12 ft. in the storeroom. The rolls are trucked along the floor with an ordinary two-wheel hand truck, and dumped on to the elevating platform of the stacker. In this way the work is done with half as many men and half the time formerly required.

7 *Rubber.* A rubber company uses hand lifts for handling box-carton material. This comes into the storeroom by chutes and is piled on platforms and then moved by hand lifts to the storage space. When needed for printing the right sizes are picked out by platform loads and taken up to the press room. As the sheets of box board come off the press, they are placed on platforms and moved by hand lifts to the fastening machine which secures the sides and ends together. The lifts and platforms have been found superior to a conveyor.

8 *Stone, Clay, and Glass Products.* One concern uses a stacker for piling bath tubs four high instead of standing them on end as formerly. More than double the number of bath tubs are now stored on the same floor space, and this has paid for the stacker many times over.

A pottery company uses 10 hand lifts in two of their processes as follows: (1) After the pottery ware is sanded in the green room, it is put on boards about 6 ft. long and then placed on peg racks mounted on platforms. There are about 12 boards to a rack. The kiln man then takes it to the kiln. Then the ware is taken from the boards and placed in saggers (clay receptacles or crucibles). The ware is then put in the bisque kiln which finishes this operation. (2) After the ware is dipped and glazed it is put through the drier, placed on boards, and then 16 boards are put on each rack. The truck then takes the loaded rack to the gloss kiln. The old method was to have a man take one board at a time to the gloss kiln after the dipping. The men are on piece work but the management figures that the lifts still make money for them by increasing the amount of pieces produced each day.

9 *Textiles.* One dye works uses a stacker to hoist rolls of cloth up to shelves. Each roll weighs about 150 lb. Formerly these were piled only two tiers high. Now the highest is about 9 ft. from the floor, more than doubling the storage space available, which alone would be a big item. Further, four men were

[3] President, Lewis-Shepard Company, Watertown, Mass.

formerly required to do the work that is now done by two men, and by one at times.

In another dye house hot dyestuff in metal barrels is moved about on platforms by one man. Previously two were required to move these barrels, and they were occasionally scalded by hot dye slopping over.

10 *Warehousing and Distribution.* In one cold-storage building when fruit arrives by freight car, steel-leg platforms taken into the car and loaded, are hauled on hand lifts to the elevator, hoisted to the next floor, and then carried into the cold-storage room. Here a stacker picks up the loaded platform and hoists the load to a shelf where it is unloaded. The fruit has only been handled once. Three men now do what formerly required six.

An ice and cold-storage company uses lift trucks in the place of ordinary four-wheel trucks in handling crates, baskets, barrels, etc., that arrive at its warehouse by truck, wagons, and freight cars. Here the platforms and lift trucks are not used to save rehandling, and yet pay. It formerly cost about $100 per year for new casters on ordinary four-wheel trucks, and the lifts and platforms save this expense as well as speed up the unloading of automobiles, wagons, and freight cars, as they keep on hand a lot of platforms and the men are not idle waiting for ordinary four-wheel trucks to be unloaded and return again to be loaded.

The next two or three years will demand efficiency in management. There is no greater opportunity, the writer believes, to effect savings than by reduction in the present cost of handling materials.

M. W. Potts.[4] The author mentions safety. Material-handling equipment greatly increases the safety factor in a plant. It eliminates the accident hazard. Engineers should vigorously oppose the idea that material-handling equipment has to pay for itself in six months or a year. No other piece of equipment is bought on that basis. It is true in most cases, but it should be allowed two years or even more to pay for itself.

Six years ago the speaker recommended a certain installation of material-handling equipment in a plant in which he was working. The other day he had the pleasure of quoting them prices on equipment amounting to $13,000. The company has been losing $8000 a year for six years—$48,000 in all, which would have paid for the equipment two or three times.

W. C. Steubing.[5] When American industries first adopted the lift-truck system for their production departments and found that they saved up to 90 per cent of their former costs of handling, they extended its use to shipping on skids. They reasoned that if such great economies could be accomplished for inside transportation it could be tied up effectively with outside transportation. The principle involved was the elimination of unnecessary loading and unloading or rehandling.

Outside transportation, which included handling of materials at terminals, has been very costly. For example, the New York Central Railroad as a water-level route reported that it cost the road 74 cents to move a ton 250 miles, 75 cents to handle that same ton in loading on to the cars, and 75 cents to unload it—two-thirds of the cost being involved in the handling of the materials and only one-third in the actual transportation thereof.

The paper mills were the first to recognize the savings that could be effected for the consumer by tying up the lift-truck system with outside transportation. The Champion Coated Paper Company, of Hamilton, Ohio, inaugurated the idea for the shipping of their paper on skids. At first they used a substantial skid or platform that was to be returned to them, and invoiced it to the consignee on memorandum account at $25 per skid. Later they shipped their paper on nailed wood skids, with the load wrapped and strapped to the platform. The skid was made the exact size of the sheets, for better protection and closer packing in the cars. Formerly a case cost the company $4. The nailed wood skid cost them $2.50, but they could stack two and one-half times the load of a case on a skid, the relative cost of cases therefore being $10 as compared to a skid at $2.50.

But the greatest saving resulted through quick handling, it requiring but 40 per cent of the time to load a car with paper on skids as compared to loading in cases. Furthermore, it was possible to get the maximum weight in a car, reducing the freight, and as large sums were saved by the company in loading their material in this manner, it was in many cases able to reduce the price of its paper from one-fourth to one-half cent per pound to the consumer—aside from the economies the consumer effected by quick unloading of cars. The nailed wood skid was but a temporary unit for quick shipment, and was eventually replaced by the paper consumer with a more substantial skid. Various mills now ship their paper on skids to warehouses and consumers in various parts of the country.

Sugar is now being shipped on skids from Cuba to Atlantic seaports, but in this case a substantial platform is used so that the skids can be lifted into the hold of the ship. At the docks and warehouses the loaded skids are handled by heavy-duty lift trucks, and from there distributed to consumers.

The Great Lakes Navigation Company is effecting an enormous saving by handling of commodities that will pack closely on skids. The steamship companies recognize that their greatest cost arises where a ship is unnecessarily tied up in harbor for two or three days, and that their greatest gains come in actual transportation.

As a result of manufacturers' shipping products on skids, the railroads, which have always been slow to adopt the more modern methods applied in industry, have now accepted the application for their own use at several points. As an illustration: the C. M. & St. P. Ry. Purchases and Stores Division are loading their cars with supplies and equipment mounted on skids. Results show that for the coming year they will ship a tonnage to their various shops, terminals, etc., in 35,000 to 50,000 cars as compared to 77,000 cars during the past years. The minimum saving of 27,000 cars per year will effect such enormous economies as to make the cost of the lift-truck system insignificant. Furthermore, their savings on man power for loading and unloading will amount to 60 per cent of their former costs. They have adopted a standard skid that can be handled by electric lift trucks or hand lift trucks—the electric lift trucks being used at the main depot for the long hauls and the hand lift trucks for the short hauls. The hand lift trucks will also be used at the smaller shops or stations where there would be insufficient moving to justify the electric units. Their aim is to systematize their whole road with this method of handling.

The lift truck is a trackless crane, able to handle crane loads to any part of a building or outside, wherever there is a roadway to sustain that load. The orderly method of having loads mounted on skids, available for quick movement, has permitted in many cases the loading of cars within one day where otherwise it required two or three days. The method provides for quicker turnover of inventory with a smaller investment in stock, consequently greater profit.

One of its outstanding qualities is that it has proved to be one of the safest methods for handling tonnage, eliminating injury to operators, and preventing big losses in the handling of goods which has been damaged through other methods. Witness the shipping of sheet metal to automobile-body plants. These sheets must be free from blemish and are carefully inspected.

[4] Flushing, L. I., N. Y. Assoc-Mem. A.S.M.E.

[5] President, Steubing Cowan Co., Cincinnati, Ohio.

Through the lift-truck system the sheets are inspected at the time they leave the machines in the mill and placed upon a platform and then moved to a car and lowered away on intermediate supports to permit hand lift trucks to take the load and move it to the end of the car and place it across 4 by 4-in. stringers. Formerly the inspection took place in the car and each sheet was handled separately. With the lift-truck system the loads are placed close together and properly braced with 2 by 4's. The method permits cars to be loaded with from 80,000 to 110,000 lb., securing the lowest possible freight rate and safety in handling. One large automobile plant reported that with the lift-truck system they are now able to unload a car of sheets in forty minutes that formerly required seven hours.

It is apparent that this system will be applied extensively in the coming year. Special lift-truck equipment is being produced by certain manufacturers which specifically solves these problems and reduces the handling of materials from 60 to 90 per cent over former methods.

William F. Hunt.[6] It seems to me that the paper brings to the foreground the very important fact that the cost of handling material is an item in unit costs which needs and should receive increasing attention from the factory manager. I should like to suggest that the author consider the advisability of emphasizing in his paper another item, possibly under the paragraph, "Delivering Material to Worker," that factor being that of the convenience of receipt and dispatch affected by the location and the ease of transfer to and from the particular manufacturing operation for which the material is brought to the workman.

Frank G. Raymant.[7] The elimination of hand labor is receiving ever-increasing attention in Canadian industry. With few exceptions production in this country has not yet reached the stage of progressive manufacture and assembly, but correct materials-handling methods as applied to the handling of bulk materials are resulting in unlooked-for savings. This is especially true where bundles made up of many small pieces are received. The writer can recall the recent case of a company manufacturing steel springs where, in unloading flat bar stock alone, the installation of two electric cranes and a twin-hook hoist result in a saving of approximately $350 per month. With the increase in capacity of the plant thus made possible, prospective business indicates that the saving will shortly be well over $500 per month. The improved method eliminates the services of over three men. One hundred dollars per shipment formerly allowed for demurrage is an added saving due to the rapidity with which the cars can be unloaded. With the same floor space, storage is increased threefold, and by adopting an improved system of tagging and having the steel shipped in bundles which are left intact until taken to the machines, inventory is greatly facilitated. A saving equal to unloading is presented in feeding the machines from storage.

A similar problem in the handling of large quantities of lumber was recently solved by the installation of an electric gantry crane in conjunction with an electric transfer crane which feeds the numerous bays of the storage yard. Previously each stick of lumber was handled individually five times between the cars and shop, two men being required for each operation. With the new system the lumber is piled in standard-size piles on the wagons and further manual handling is eliminated by the electric crane. The crane is used to feed the dry kilns and the three floors of the shop. Storage per square foot is greatly increased and inventory is comparatively simple.

Many similar cases exist where manual labor has been reduced to a minimum or entirely eliminated. Unfortunately instances still remain where a proper diagnosis of present handling conditions and the application of proper equipment would mean yearly savings of many times the value of the investment. Another point worthy of mention is the satisfactory results to be obtained where the source of supply and the purchaser agree upon shipping material in standard-size bundles which facilitate handling and are a source of profit to all parties concerned. As the executive becomes more familiar with the indirect as well as the direct savings with which it is possible to increase his profits by increasing the efficiency of his materials handling, he will take a greater interest and activity to this end.

Merritt Lum.[8] One point I should like to emphasize is the making sure on our part of such standardization of heights, and such possible standardization of widths of platforms as will make it possible for the machine designer to design his machine to fit the material-handling equipment as he finds it today, or as it may become improved tomorrow.

A second point is the effect of the leaders in the use of material-handling equipment upon those users who are less progressive. The author might have carried farther his point of shipment on platforms by referring to certain industries and certain progressive firms where the buyers are specifying the manner by which the material must be shipped. I am thinking of such companies as the Hudson Motor Company, which, I understand, specify that material coming to them must come on skid platforms, and packed in cars in a certain way so that they may find it most convenient and economical to handle when it comes to them.

A third point is the simplicity of cost figuring. Wherever we devise a method of figuring costs of material handling we must realize that method must fit the purpose of the manufacturer or the factory superintendent or the manager as well as the engineer. Unless we get our formulas simple and put them in terms that are quickly grasped by the man who is going to buy the material, then we confuse rather than help the situation.

A fourth point is the recognition of material handling as a special function of an industrial plant, which should be in the hands of some man who is wholly responsible or at least has a major responsibility for such work.

A final point is the getting together of manufacturers, and their agreeing on the limitations and proper fields of application of the various types of equipment. Unless we begin to develop a mutuality of interest among manufacturers, then the buyer will continue to be confused and disappointed when, after purchase, he find he has been oversold on a type of equipment, whereas another type could do the work much better. That situation reacts on all types of equipment, and the Materials Handling Division has a grave responsibility in the matter.

J. C. Gillette.[9] In the Edgewater plant of our company which we have rebuilt and increased in capacity about 300 per cent, with the exception of moving from the basement to the fourth floor, practically none of our material moves without being worked on. We have something like a mile and a half of conveyors, practically all roll-way conveyors. Our work progresses through the plant with the belt speeds close to 25 to 30 ft. per min. with a piece of work on every foot of the belt, in some cases four abreast. Operations are performed on each

[6] Consulting Engineer, New York, N. Y. Life Assoc. A.S.M.E.

[7] Materials-Handling Engineer, Riley Engineering & Supply Co., Limited, Toronto, Can. Jun. A.S.M.E.

[8] McGraw-Hill Publishing Co., New York, N. Y.

[9] Works Engineer, National Carbon Co., Cleveland, Ohio. Mem. A.S.M.E.

piece of work in practically every case just as close as the operators can stand conveniently.

Ours is practically a new problem, but comparing it with the old problem of making the 6-in. dry cell, the labor and handling cost is something around one-fifth of what it would have been under the old tray and truck method. I believe that one of the points that should have been included in the paper is "Fabrication of Materials in Progress," making nine points instead of eight.

H. V. Coes.[10] I wish that the author had brought out another subject that goes hand in hand and is practically a product of material handling. Material handling is more than just purely the question of handling material—if properly set up and coordinated it automatically schedules production. The great automobile plants in Detroit do not have complicated schedule boards or anything of that kind. If the material does not show up at a certain place, it stares one in the face somewhere else. They do not need any record or clerks to refer to. The situation is right there in front of them.

It seems to be characteristic of human nature never to arrive at a simple solution at the start. We ought to direct our thinking toward getting things less complicated and reducing our repair bills and maintenance charges. Much of the equipment sold is not designed apparently to stand the hard usage it will naturally receive, and the maintenance charges in consequence are high.

I should like to direct the attention of the Materials Handling Division to that phase of our work and to bring out concrete examples whereby any number of dissimilar units may be coordinated in material handling. In our plant we are using overhead cranes, electric trucks, gravity conveyors, roller conveyors, and they are operated as one system.

We should have available more data on maintenance charges of material-handling equipment. Then we could aid those who design and manufacture equipment by bringing back to them what our experience has been in the actual, everyday use of the equipment.

Next comes the question, "How can we still further utilize material-handling equipment to automatically schedule production?"

Charles H. Bigelow.[11] The economics of handling should be considered, because a given apparatus may be too expensive for the work to be done or the savings to be made. Another point is the geographical layout: What might be good for one place might be entirely unsatisfactory in another location. In coal handling, for example, where the coal is delivered above, it can be dropped by gravity to the boiler room. If, however, it is delivered below the boiler room it is necessary to elevate it.

A question came up about handling steel to the shears. The steel comes on open flat cars, in heavy bundles. A locomotive crane lifts the steel up and places it in piles, from which it is taken by the crane to the shears as needed. The idea was to have a conveyor run along the end of the piles and carry the bars up, but the question arose as to how to get the bars turned around and placed on the conveyor, and the best way seemed to be to use the crane to lift and turn the steel around, and then the crane might as well run two or three hundred feet further and drop the steel into the shears. We did not put that system in, although it looked very nice on paper.

In our plant, at present, we are using roller conveyors to slide the material from one machine to another in the shops. We are using a portable conveyor for loading heavy scrap. We shovel it on. The first car we loaded cost us about 33 cents a ton because the material kept rolling back down the conveyor, requiring rehandling. By reducing the speed we found we could load the material into the car at 24 cents a ton. Although the conveyor ran slower it was impossible to overload it, and the material did not have to be rehandled.

D. R. Long.[12] One speaker mentioned the matter of coöperating with manufacturers in using suitable containers to facilitate materials handling. In two instances by doing that our plant saved some money. We make paper tubes, rolling linoleum on them, and use about three and a half carloads of paper a week. In the center of the roll a couple of inches of paper were wasted, and on the outside, three or four layers were torn. So we started to use steel cores and steel bands on the edges of the outside of the rolls, thus cutting the loss from 10 per cent to $2^1/_2$ per cent in handling.

We use considerable rosin which is shipped from Georgia in barrels. We used to pay for the barrels, for the freight, and in addition for gross weight. The loss was high because the rosin sticks to the barrel, and the staves are very difficult to burn without smoke.

We cooperated with a manufacturer of tank cars, and he furnished us with one to experiment with. Now we are using tank cars entirely. The railroad pays us a cent and a half a mile for the tank cars, and we pay the usual freight rates for rosin. The savings we have made are the price of the barrel, the rosin that sticks to the wood, and the trouble of disposing of the wooden barrels.

Very often standard parts of material-handling equipment can be used to manufacture a special handling device. To illustrate, we needed a special low-head crane, lower than any manufactured at that time, and sent out specifications to four manfacturers of cranes. One of them sent a representative to our plant to see if the specifications could be changed. He learned that this was impossible, but in going through the plant he saw a piece of equipment he had furnished. This gave him an idea, and with it and some extra parts he made a special crane. Each part used was a standard piece of equipment, but assembled in just a little different way.

K. D. Hamilton.[13] Shoes today are being fabricated in the process of transportation, and I believe in ten years many shoes will be made on conveyors as automobiles are made, with the exception of high-grade shoes and extreme styles.

We recently installed a coal conveyor, and cut the cost of handling from a dollar down to six cents a ton. We were interested in ash disposal and found that contractors will pay good money for cinders. Instead of putting them in the dump we are now making a net saving of $600 a year on the disposal of cinders.

We use sixty Hudson cars for the transportation of salesmen, electric trucks in the plant, and lift trucks for conveying sole leather; we have 600 ft. of conveyor in the cutting department where small patterns are cut.

This old industry, with customs of fifty years ago, is modernizing, and will prove to be a very fertile field for conveyor installation in the next four or five years.

The Author. A number of points which deserve emphasis have been brought out in the discussion. To the eight view-

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[11] Plant Engineer, Spicer Mfg. Corp., South Plainfield, N. J. Mem. A.S.M.E.

[12] Chief Engineer, Armstrong Cork Co., Lancaster, Pa. Mem. A.S.M.E.

[13] Mechanical Engineer, Walk-Over Shoe Company, Brockton, Mass. Mem. A.S.M.E.

points from which I considered the materials-handling problem in my paper, a ninth, as suggested by Mr. Coes, could well be added. It is "the influence of materials handling on the scheduling of production." Materials-handling methods where properly planned, coordinated, and supervised will help considerably toward the automatic scheduling of production, thus greatly reducing the expense of operating the planning department.

I am pleased that Mr. Lum referred to the fact that the field for each type of handling equipment is limited. Too often equipment is recommended and installed on jobs that could be more efficiently handled by another type of equipment.

It is also well to bear in mind that the materials-handling problem is important in the small plant as well as in the large one. The size of the plant may have an important bearing on the type of equipment to be selected. In the case of the smaller plant which is expected to expand, the handling system should be such that it can be expanded conveniently as required, without discarding any of the old equipment and at reasonable cost.

The author is in full accord with Mr. Hagemann in his statement that the goal has not necessarily been reached when the correct handling equipment has been installed. It is quite as important that the equipment be properly used and that full use be made of it. The author has seen many instances where the equipment was incorrectly used, greatly lowering its usefulness, and he has found many cases where the equipment was used to only a fraction of its full usefulness.

The specific savings mentioned by Messrs. Hamilton, Raymant, and Steubing as being accomplished in certain instances due to the improvement of materials-handling equipment or methods are typical of what can be done, and it is not surprising that materials handling is now being recognized as an important aid to production and a factor in which great possibilities exist for the reduction of production costs.

# Cargo Cranes—Types Available, Factors Governing Selection, and Latest Developments

By BERNARD DUNELL,[1] VANCOUVER, B. C.

*In this paper the author discusses the several types of cranes used on docks for removing cargoes from ships and placing the articles handled, that is, crates, barrels, bundles, etc., at the points desired. Two general types of cargoes must be handled: namely, bulk cargo and general cargo. The disadvantages of some of the common types are mentioned, and the manner in which these have been eliminated in later designs are pointed out. The types of loads best handled by different types of equipment are mentioned, and recommendations as to proper equipment are made. It is shown that, while in some cases as high as 50 tons must be lifted, the most popular general-cargo crane is of from three to five tons' capacity. The author emphasizes the importance of proper attention to dock conditions in the determination of wheel loads, and therefore, the crane capacity, in the case of existing docks, and where new construction is contemplated the desirability of adequate strength to take care of the maximum load likely to be imposed. The hoisting rope receives considerable attention in the paper. The disadvantages of the two-strand fall are pointed out, and it is recommended that it be avoided wherever possible. A disadvantage of the ordinary luffing crane is that when the jib is luffed in the load suspended from the jib head is simultaneously raised, resulting in wasted work and requiring a more powerful motor than otherwise would be necessary. Level-luffing cranes are described which overcome this objectionable feature and permit more flexible operation. The various arrangements of compensators and counterweights to permit this are described.*

THE term "cargo" covers all sea-borne merchandise and may be sub-divided into:

1 Bulk cargo—grain, coal, ore, timber, oil, etc., or any other commodity, only one of which is carried by the ship on any particular voyage

2 General cargo—merchandise of all kinds, either packed in containers, baled or handled loose, a great variety of materials going into the making of one cargo.

It is the intention of this paper to deal only with dock cranes as applied to the handling of general cargoes, and not to include any of the special class of appliances which have been devised for loading and unloading bulk cargoes. In the latter class are included such machines as the Hulet unloader, coal transporters, grain elevator legs, etc. These devices are in each case designed for handling one particular class of material, the selection of the most suitable machine being determined very largely by this consideration only. For the work they are intended to perform they cannot be excelled, but their field of usefulness is confined to the material under consideration.

## Handling of General Cargo

In the handling of general cargo a very much broader view in analyzing the situation has to be taken. Diversity of shape, size and weight precludes the possiblity of using elevators or conveyors to any great extent, while the necessity of sorting and piling in alloted places on the wharf makes the transporter, with its rather limited area of discharge, unsuitable. The transporters here referred to are those of the traveling type, but without a swing or radial motion; those having a radial motion and sometimes referred to as straight-line cranes will be dealt with later.

In selecting the most economical crane for handling general cargo it must be borne in mind that individual pieces will vary in weight from a fraction of a ton up to perhaps 50 tons or over. The frequency with which 50-ton lifts are likely to be encountered is exceedingly low, also 10-ton lifts are quite uncommon, so that it would be out of reason to install on any single dock a number of cranes capable of handling such weights. The question then arises: What is the most economical capacity of crane to use? This question cannot be answered with any certainty, as no one can foretell what the average weights to be handled will be. It can be stated, however, that the most popular general-cargo cranes in use at present are of from three to five tons' capacity.

Loads above this are not so very frequently encountered, and should be handled by ships gear or by a heavy-lift crane with which every port of any magnitude should be equipped. If ships gear is used for heavier lifts than five tons it generally means that a special derrick boom has to be rigged, as the derricks usually employed will not lift such weights. Many tramp steamers carry on deck a heavier boom and tackle which can be rigged on the mast for taking extra-heavy lifts. The erection of this special equipment entails both expense and delay, which should not be required in any well-equipped port.

In addition to considering the different weights which have to be handled, the great variety of sizes must be considered. This does not apply so much to case or baled goods, but is particularly noticeable as regards the type of crane to be adopted when it comes to loading or unloading such material as steel rails, structural sections, iron rods, and long timbers. In lifting material of this nature into, or from, the hold of a ship it is necessary to place the slings in such a position that the load will assume a more or less vertical position when lifted. The result is that a good portion of the load will project above the hook, and when in its highest position will project above the hoisting pulley.

In the case of derricking jib cranes, either level luffing or otherwise, this is not important, as the jib swings with the load; but with the transporter or straight-line crane, that portion of the load projecting above the trolley path is in danger of fouling the boom as the trolley is racked in or out. A slight shock to a bundle of rails, rods or angles will often cause the load to slip through the sling.

A further point to be considered in the handling of general cargo lies in the fact that different consignments are often loaded promiscuously into the sling nets and have to be sorted as to marks and numbers when landed on the wharf so that each consignment can be piled in its allotted place in the sheds or on the dock. Then again it may be required to take one class of material from one part of a ship's hold and another class from a different part of the same hold and deliver the loads alternately to two separate shed doors. In order that the same crane may be capable of this duty it should have a wide area of pick-up and discharge without delay being occasioned in reaching these areas.

An important consideration in selecting a wharf crane is the

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wheel loads which the structure of the wharf will be subjected to. As will be seen from the accompanying illustrations these wheel loads may vary to a very considerable degree in different makes of cranes, although they may be of the same capacity, outreach and rail gage. These wheel loads are not quite so important in determining the selection of crane in cases where a new wharf is to be built, as provision can be made for whatever loading is required, but in cases where cranes are to be installed on existing wharves great care must be taken to see that the maximum wheel loads will not be in excess of the safe working loads the wharf structure is good for. In any case the crane with the smallest

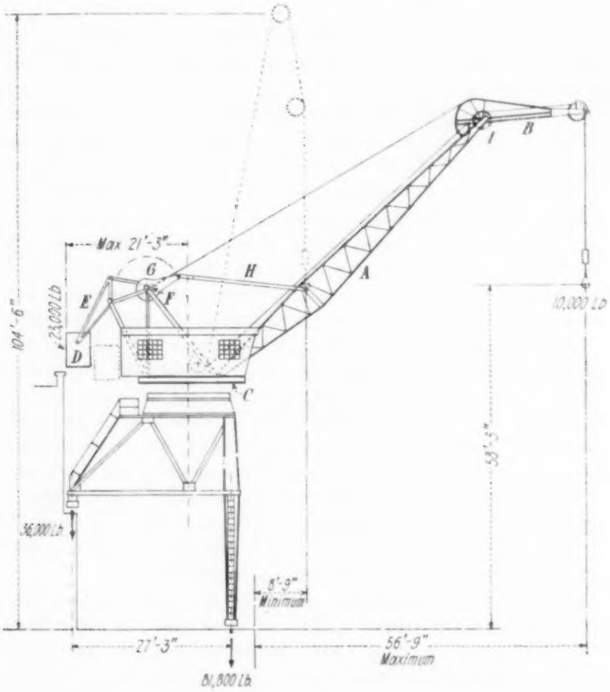


Fig. 1 Level-Luffing Type of Crane

wheel loads, other things being equal, has a decided advantage over others. Any additional strength to a wharf or building, whether new or otherwise, required by reason of the wheel loads it is subjected to should be debited against the crane when selection is being made.

The hoisting rope of a modern cargo crane should lift on a single fall of rope, even when dealing with loads as high as five tons, as the handling of a snatch block in the hold of a vessel is a clumsy and aggravating process and is strongly objected to by stevedores and laborers. The bight formed by the snatch block is very liable to catch in anything that may project into the hold of the ship, also the two strands of the hoisting rope may possibly get twisted one around the other and require untwisting before the load is picked up. This is one of the disadvantages of the type of crane shown in Figs. 7 and 8.

How the different types of cranes fit in with the above requirements will be seen later on.

Before coming to a description of any of the modern wharf cranes at present in use it might not be amiss to review briefly some of the earlier types and the circumstances which have lead to their betterment.

## Early Wharf Cranes

Omitting the very primitive contrivances, we find that the earlier wharf cranes were very often stationary jib cranes having a fixed radius, either steam or hydraulically driven. These had many disadvantages, as can easily be seen, and if in use today would not compare favorably as to speed with any ships gear. They had their use, however, in the days when sailing ships were in the preponderance.

A more recent development was the traveling portal crane having a jib capable of being luffed as well as swinging. In this type all the required motions were present, but there was still much left to be desired. Those that were steam driven had the disadvantage of the time wasted in getting up steam, the necessity of constant firing, supplying of coal and taking away of ashes. Hydraulic power, on the other hand, had to be transmitted from a central source to the crane through a pipe line, and although hydraulic cranes were made to travel along wharves to a certain extent the amount of travel was very limited. Also, there was the trouble of frozen pipes, cylinders, etc.

Next came the electric crane, first operating on direct current, then alternating current. These constituted a big step in advance of the steam or hydraulic crane. At the same time

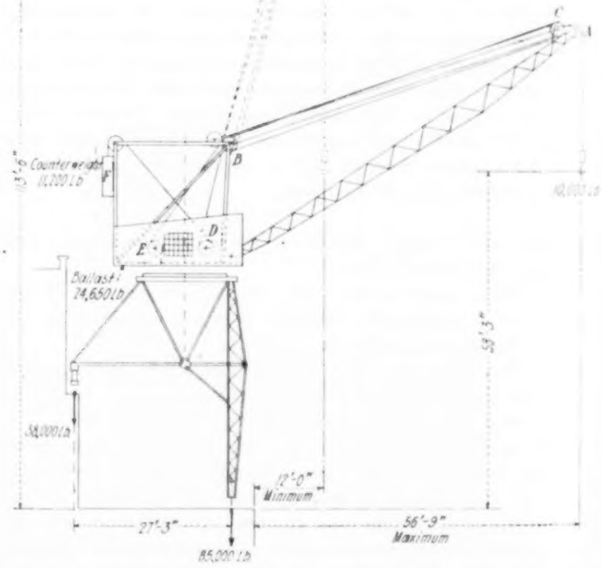


Fig. 2 Level-Luffing Type of Crane with Special Reaving of Hoisting Rope in Conjunction with Particular Arrangement of Centers of Jib-Head Sheaves, Fixed Sheaves on Superstructure End of Jib-Foot Pivot

that wharf cranes had been advancing, however, a certain amount of improvement had been made in ships winches and the methods of using them, so that there was not a very great difference in the speed of handling cargo by cranes as compared with ships gear.

In spite of the fact that up to quite recently wharf cargo cranes did not show much advantage as to speed over ships gear, they still formed a very important part of the dock equipment of many large ports. One of the principal reasons for this being that, providing wharf cranes are available, a ship on arriving at her home port for discharging is not under the necessity of keeping up a head of steam, with all the attendant expenses, simply for the purpose of working the cargo winches. Bearing this in mind, and remembering that up to 1921 nearly 35 per

cent of the world's ocean tonnage was carried in British ships, and 60 per cent in ships of European register, it is hardly surprising that it is in Europe that we find the cargo crane most highly developed.

### Luffing Cranes

One of the chief disadvantages which the ordinary luffing crane works under is that when the jib is luffed in the load suspended from the jib head is simultaneously raised; conversely, as the jib is let out the load falls by a corresponding amount. This is all wasted work and means an unnecessarily large motor to work the luffing gear. A further result is that the jib is luffed in or out as little as possible and the flexibility of the crane is seriously impaired.

To overcome this objection a number of different designs of a type of crane known as the "level luffing" crane have been developed. In all cranes of this type a compensating gear in some form or another is provided whereby the load is made to travel along a horizontal path irrespective of the rise and fall of the hoisting pulley caused by the luffing in or out of the jib. A well-known make of this type is illustrated in Fig. 1.

The distinctive feature of this compensating gear, which pro-

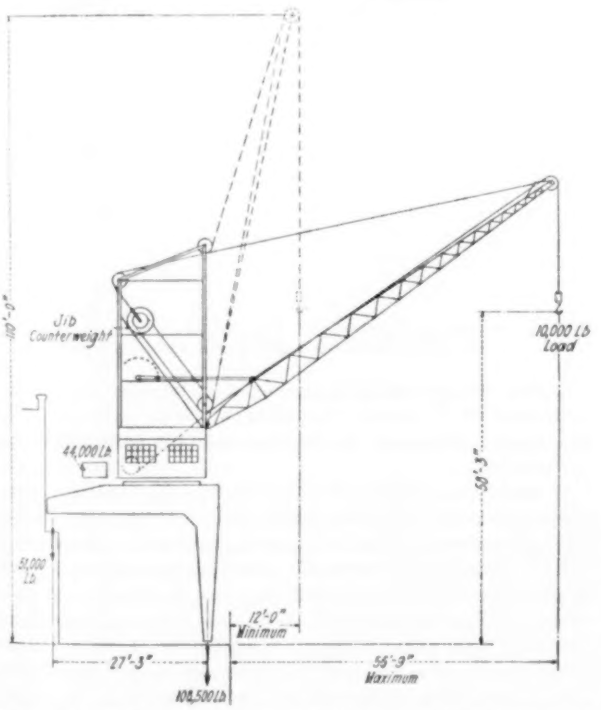


Fig. 3 Level-Luffing Type of Crane with Counterweight Arrangement for Paying Out Required Amount of Rope to Give Level Luffing

vides the level luffing motion, lies in the fact that the crane jib is composed of two sections; the outermost of which is folded in toward the other automatically as the load is luffed in, and vice versa. During the operation of luffing, therefore, as the lower section of the jib is raised at a steeper and steeper angle, the outer end folds down; the relative motions being such that the sheave at the extreme end of the jib travels along a horizontal path, the suspended load doing likewise.

Referring to Fig. 1, which illustrates a 5-ton crane of the above type, it will be seen that the main jib $A$ carries at its outer end an extension jib $B$ which is roughly one-quarter the length of $A$. The main jib is of lattice construction and is pivoted at its heel to the revolving platform.

The weight of the jib is balanced by the counterweight $D$ which is connected by the bell cranks $E$ to cranks on the shaft $F$. On the same shafts are the cranks $G$ which actuate the jib through the links $H$.

Returning to the extension jib $B$ which is pivoted on the same shaft as the sheave $I$, it will be seen that its construction includes a member curved around the inner end of $B$ in a loop. In plan, there are two of these curved members which are channel-shaped in section, in each of which a guy rope is secured and anchored back to the shaft $F$. When the jib rises $I$ approaches $F$,

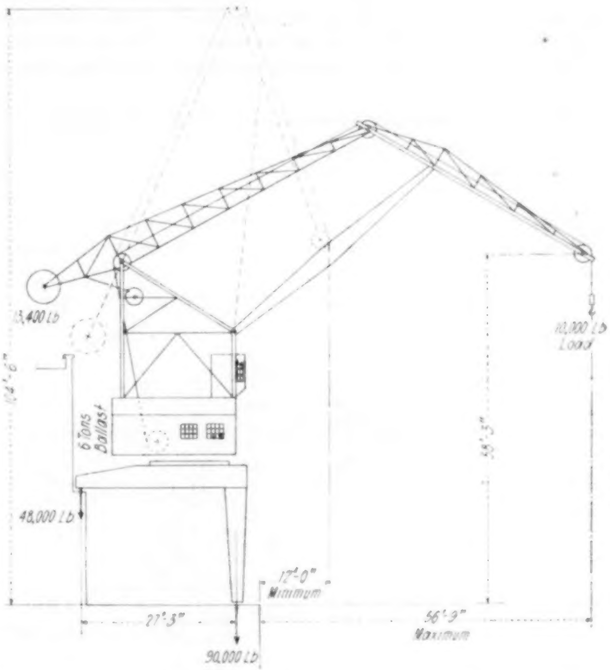


Fig. 4 German Design on Order of Pantograph with Level-Luffing Feature

so that the guy ropes allow the extension jib to rotate downward, the guy ropes at the same time wrapping around the curved channels. These channels are not bent to a true circle but are of special form so that the folding in of the extension jib is constrained in such a way that the load travels in a straight line. The small amount of hoisting rope which is paid out during luffing, due to the hoisting barrel not being concentric with the foot of the main jib, is compensated for by this means.

As the load being lifted is neither raised nor lowered during luffing operations, it will readily be seen that the power required is only that which is necesary to overcome the inertia of the parts moved.

The balancing of the dead weight of the jib also has a bearing on the ease or otherwise with which luffing can be carried out. In the type of crane shown in Fig. 1, the counterweight $D$ moves simultaneously in the opposite direction to the jib, so that the two are always very nearly in balance.

The value of this balanced level-luffing system will be appreciated from the fact that on two cranes of similar capacity and radius, that fitted with this gear will have a luffing motor of about one-tenth the power of the other, and when it is considered that in most cases the jib is luffed with every lift, it will be realized that an enormous saving in power is effected.

### Discussion of Operation

The crane shown in Fig. 1 has a maximum outreach, measured

from the face of the dock, of 56 ft. 9 in., which is equivalent to a radius, measured from the crane center, of 76 ft. 9 in., and has a minimum radius of 11 ft. 3 in.; that is to say, it can pick up or deposit its load anywhere between two circles having diameters of 153 ft. 6 in., and 22 ft. 6 in., and can place its load not only on the dock itself but also on upper floors of the sheds if so desired, a point in its favor, as compared with cranes illustrated in Figs. 7 and 8.

The jib with its counterweight and other parts which go to form the revolving portion of the crane are made as light as is compatible with safety, so that with a hoisting speed of 175 ft. per min. for 5 tons, or 300 ft. per min. for $2^1/_2$ tons and with a high slewing speed, which at the maximum is 450 ft. per min., quick action is obtained in transporting a load from one point to another.

The wheel loads indicated in the illustrations are directly comparable, as all the cranes except those shown in Figs. 5 and 6 are exactly similar as far as loads, outreach from face of dock, and speed are concerned; except also that the crane shown in Fig. 7 is designed for hoisting speeds of 100 ft. per min. for 5 tons and 200 ft. per min. for $2^1/_2$ tons, as against 175 and 300 ft. per min., respectively, for the other cranes. This difference makes the impact component of the total wheel load slightly less for the crane in Fig. 7 than it would be if the higher hoisting speeds were used.

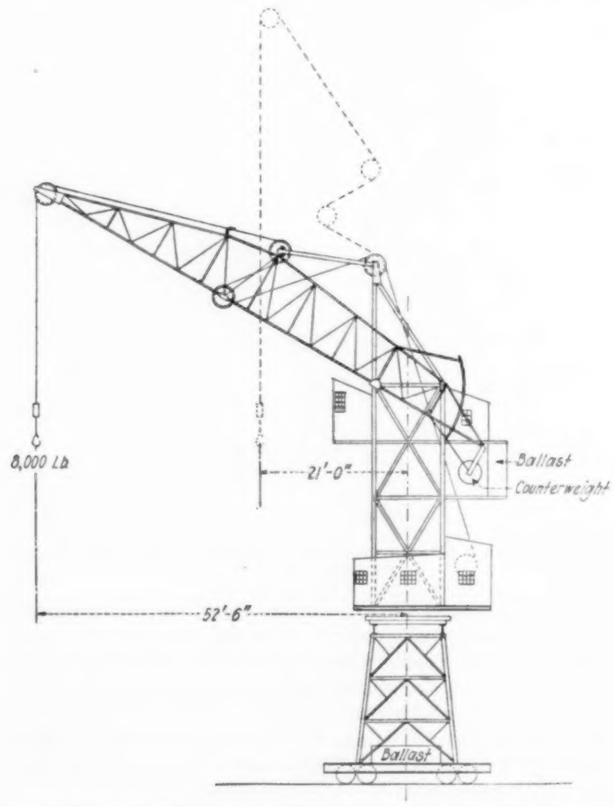


Fig. 5 Crane in Which Luffing Is Accomplished by Means of Pinions Engaging in Segmental Racks on Each Side of the Jib

In Europe level-luffing cargo cranes are now almost exclusively used, and other designs than that shown in Fig. 1 have been evolved. The arrangement for obtaining the level-luffing motion in the crane shown in Fig. 2 consists of a special reaving of the hoisting rope in conjunction with a particular arrangement of the centers of the jib-head sheaves, the fixed sheaves on the superstructure, and the jib-foot pivot. The hoisting rope after passing over the sheave $A$ at the extreme end of the jib is taken around one of the sheaves at $B$, thence back to one of the sheaves at $C$, again over a second sheave at $B$, and thence to the hoisting barrel $E$. When luffing-in the jib from one radius to another, the distance between $A$ and $B$ decreases by an amount equal to one-third of the vertical raise of the jib head. Since there are three falls of rope between $A$ and $B$, the amount of rope paid out is three times the amount by which the distance $AB$ has been decreased, and, therefore, compensates for the vertical rise of $A$.

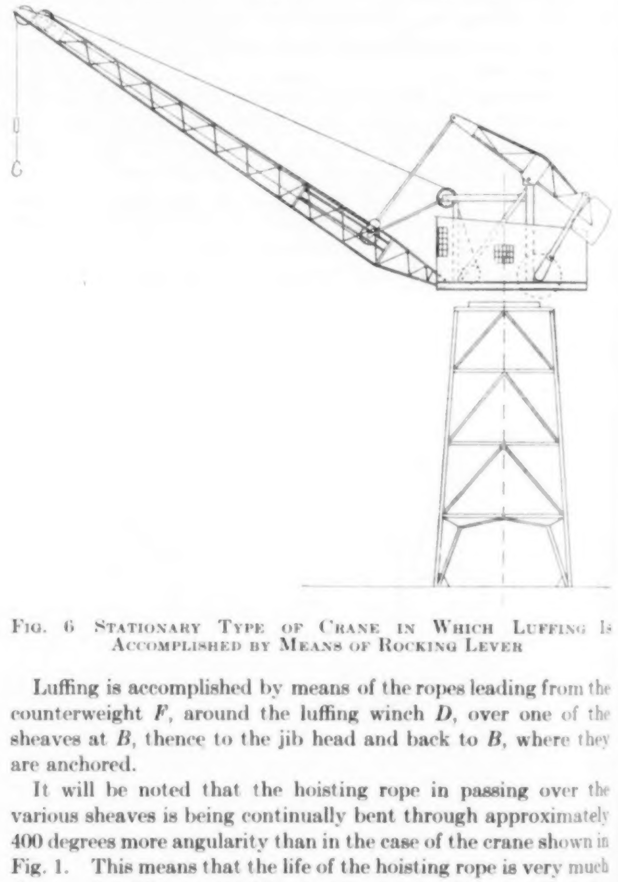

Fig. 6 Stationary Type of Crane in Which Luffing Is Accomplished by Means of Rocking Lever

Luffing is accomplished by means of the ropes leading from the counterweight $F$, around the luffing winch $D$, over one of the sheaves at $B$, thence to the jib head and back to $B$, where they are anchored.

It will be noted that the hoisting rope in passing over the various sheaves is being continually bent through approximately 400 degrees more angularity than in the case of the crane shown in Fig. 1. This means that the life of the hoisting rope is very much shortened, with a proportionate increase in the cost of maintenance. The counterweight $F$ in this crane is much lighter than that of the crane in Fig. 1. To make up for this, additional ballast is placed in the back of the operating cab, so that the total is considerably in excess of that of the first crane. Also, the crane in Fig. 2 lacks the advantage gained by the outward movement of the counterweight as in Fig. 1.

In Fig. 3 is shown another design of level-luffing crane. Here the hoisting rope, after passing round a sheave near the jib foot is taken over a sheave placed concentrically with and attached to the traveling counterweight; it is then taken back to the sheave near the jib foot and so to the hoisting barrel. As the jib is luffed in, the counterweight travels down the inclined path, thus paying out the required amount of rope to give level luffing. A crank and connecting link are used for actuating the jib.

A somewhat novel type of crane is illustrated in Fig. 4. This is of German design, in which country it has been used quite extensively. As will be seen it is on the order of a pantograph, thus obtaining the level-luffing feature.

The two cranes shown in Figs. 5 and 6 are very similar in the

means employed for obtaining the level path of travel for the hook. The hoisting rope, on its way from the jib head to the hoisting barrel, is taken in a bight round the sheave centered on the radius rod attached to the crane structure. As the jib is luffed, this sheave is made to travel along the track forming part of the jib. Except for this similarity the cranes are very different, that in Fig. 5 having the peculiarity that the lower end of the jib is so constructed that it embraces the revolving tower, and has counterweights on either side of the machinery house. Luffing

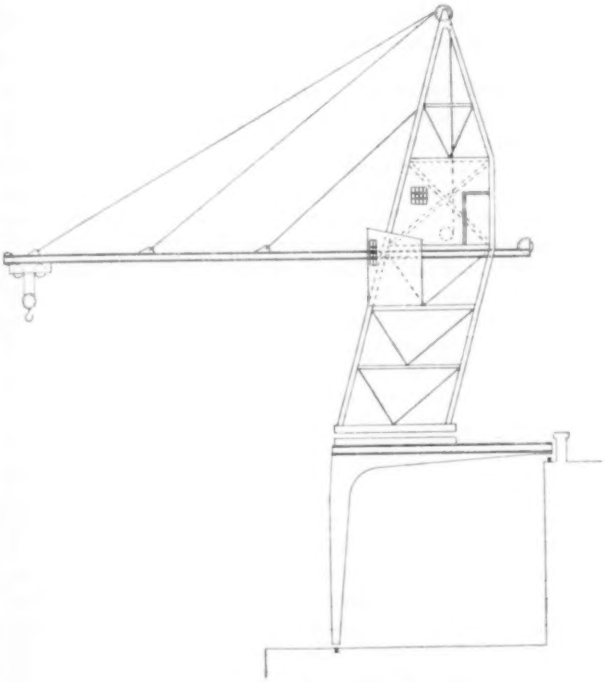

FIG. 7 TYPE OF TRANSPORTER CRANE

is done by means of pinions engaging in the segmental racks on each side of the jib.

Although the crane illustrated in Fig. 6 is of the stationary type, it could equally well be made to travel. The level-luffing motion has already been described as being accomplished by the sheave traveling up and down the path within the jib lattice work, the sheave being controlled by the radius rod. Luffing in this case is by means of a rocking lever which is attached to the jib at one end by means of a long link and at the other end is connected to a revolving crank. The rocking lever is counterweighted. An all-round motion of the luffing crank is permitted, which has the advantage of preventing any possibility of over luffing, but has the distinct disadvantage in causing confusion for the operator in his not knowing in which direction the jib will move from a point of rest. The crane in Fig. 1, although equipped with a crank-actuated luffing device, does not have the all-round motion as above described, limit switches being provided to prevent the operator luffing the jib in or out beyond certain limits. It still has the safety feature of not permitting over luffing should the limit switches fail.

In Figs. 7 and 8 are shown cranes of the transporter type, that shown in Fig. 8 having the advantage over the one in Fig. 7 in that the load may be transported to the rear of the machinery house. This is accomplished by offsetting the trolley rail from the center line of the jib by an increasing amount as the rail leaves the jib head and approaches the main structure. At the center line of rotation of the crane the trolley rail is sufficiently offset for the trolley and its load to pass the substructure. The amount of this offset determines the minimum operating radius of the crane. The type illustrated in Fig. 8, on account of the offset, approximately 17 ft., has a greater minimum radius than that in Fig. 1.

It might appear that once this type of crane had been put into position, with its jib head in the correct position over the ship's hold, a greater unloading speed could be attained than with a luffing crane, by reason of the fact that the load after being hoisted travels in a straight line to the point of discharge instead of traveling in a more or less circular path as in the latter case. It should be observed, however, that whereas the crane in Fig. 8 has a racking speed of 250 ft. per min., the slewing speed of the crane in Fig. 1 has a maximum of 450 ft. per min., and an average of 277 ft. per min.

In addition to this the level-luffing crane is almost invariably luffed at the same time that it is being slewed, in this case at a rate of 150 ft. per min., so that there is the accumulation of the two speeds.

The type of crane shown in Fig. 8 is seldom slewed through any considerable angle once it is in position, the reason being that when it is rotated it cannot describe an arc of shorter radius than the length of its jib measure from the center of the crane. As a

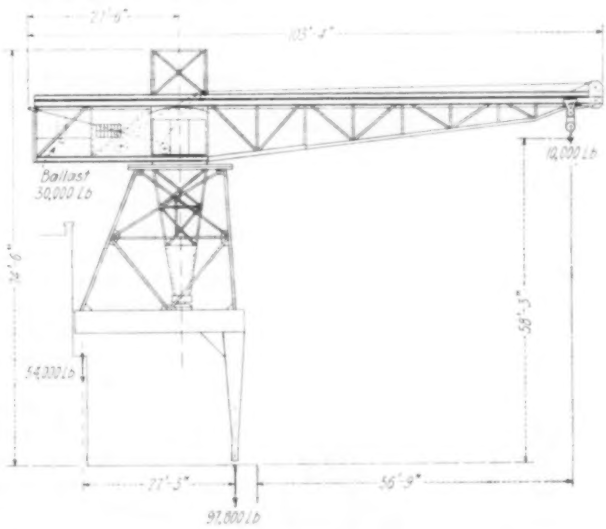


FIG. 8 TRANSPORTER CRANE IN WHICH LOAD MAY BE TRANSPORTED TO REAR OF MACHINERY HOUSE; A FEATURE NOT INCORPORATED IN THE CRANE OF FIG. 7

result it will often foul the ship rigging or upper-works on being slewed, unless it is at the same time traversed along the dock. Traversing is comparatively slow and sometimes requires clearing of the tracks before the crane can be moved. This, however, is the procedure adopted when it is desired to land loads alternately at different points on the dock. The first load is deposited in its assigned position, then after picking up the second load the crane is traversed along the dock until the second load can be dropped

TABLE 1 PRINCIPAL DATA ON CRANES ILLUSTRATED

| Fig. No. | Total weight, lb. | Hoisting speed, 10,000 lb., ft. per min. | Hoisting speed, 5000 lb., ft. per min. | Slewing speed, r.p.m. | Luffing speed, horizontally, ft. per min. | Maximum wheel loads, two-wheel bogies, lb. |
|---|---|---|---|---|---|---|
| 1 | 127,000 | 175 | 300 | 1.5 | 200 | 81,800 |
| 2 | 149,000 | 175 | 300 | 1.5 | 200 | 85,000 |
| 3 | 195,000 | 175 | 300 | 1.5 | 200 | 108,500 |
| 4 | 146,000 | 175 | 300 | 1.5 | 200 | 90,000 |
| | | | | | Racking | |
| 8 | 169,200 | 100 | 200 | 1.0 | 250 | 97,800 |

in its appointed place. While this is being done the jib head is held approximately in a fixed position over the vessel, and the cycle is then repeated as may be necessary.

From the above it will be seen that a straight-line crane is better adapted to handling material from the ship to one point at a time on the wharf rather than to different points in quick succession, as is required in sorting and piling general cargo.

The weight as shown in Table 1 is also a disadvantage of this type, not only in cost of construction but also in that a stronger and more expensive substructure is required for supporting it.

In the table are given also some of the principal data relative to the cranes illustrated, to which it should be added that they are all designed for the same load, namely, 10,000 lb., the same maximum outreach, of 56 ft. 9 in., and a hoisting height of 58 ft. 3 in., also the same rail gage, 27 ft. 3 in.

## Discussion

D. S. Beyer.[2] An important point which is not discussed in this paper is that of accessibility of parts requiring frequent inspection, repairs, lubrication, etc., and the safety of the men who must do such work.

Repairs may have to be made under difficult weather conditions, and wherever practicable, stairways should be provided. Where a ladder seems to be the only possible arrangement, it should have a safety "cage" or enclosure around it.

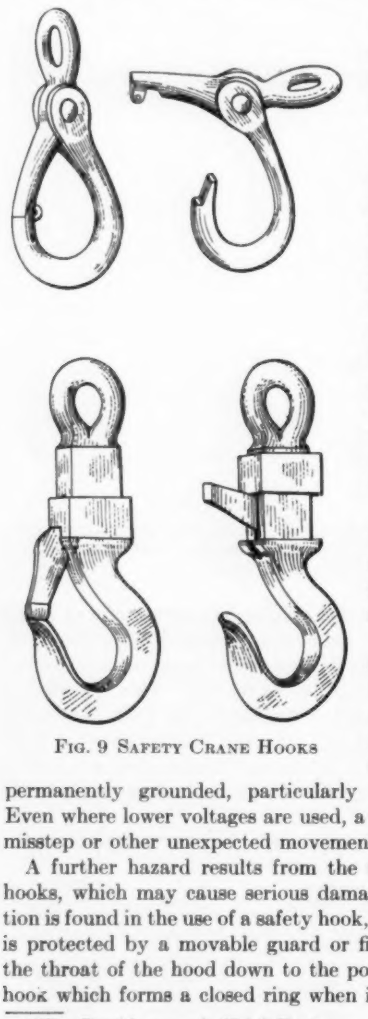

Fig. 9 Safety Crane Hooks

In many cases the provision for getting to bearings consists of a few loose planks strung here and there by riggers, or by the men who have to use them, making the work of lubrication, inspection, and repairs a constant hazard. Under such conditions this work is likely to be neglected, or injury to the men who are provided to do it may tie up the equipment.

Permanent railed walkways, with platforms at sheaves or other working points, should be provided in all cases.

Electrical equipment should be enclosed so as to prevent accidental contact with live parts. Dead metal parts such as motor frames should be permanently grounded, particularly for voltages above 220. Even where lower voltages are used, a slight shock may cause a misstep or other unexpected movement that will result in a fall.

A further hazard results from the use of ordinary open-end hooks, which may cause serious damage. An excellent precaution is found in the use of a safety hook, so designed that the point is protected by a movable guard or finger which projects from the throat of the hood down to the point, or by using a type of hook which forms a closed ring when it is in use. In the latter case the hook may be designed so that the point is supported and strengthened by the extra member which closes the hook. Illustrations of this type of hook are shown in Fig. 9 which is taken from the writer's "Industrial Accident Prevention," published by Houghton Mifflin Company, Boston.

Counterweights should be so placed in relation to the remaining equipment, as to do the least possible damage in case they should fall, and proper means of cushioning and retaining them should be provided, to prevent wrecking the equipment or endangering human life in case they should accidently drop.

Needless to say, frequent inspection of cables and other parts of the hoisting apparatus when in service is of great importance.

[2] Vice-President and Chief Engineer, Liberty Mutual Insurance Co., Boston, Mass. Mem. A.S.M.E.

Willard C. Brinton.[3] European ports use cranes for handling general cargoes for a reason not immediately apparent to most people. These ports are very old. They were built at the head of navigation in rivers when boats were small, and as ships increased in size the rivers were dredged. The bridges in many cases are very low. This makes it impossible to use floating cranes and the result is that the cranes are on the shore.

Travelers returning to New York wonder why our seaports are so far behind those in Europe in the use of cranes. They entirely overlook the fact that New York has probably more cranes than all the ports of Europe have, but that they are floating equipment instead of being on shore. The bridges being of recent construction, they are high enough to permit such equipment to pass under.

The Author. The author cannot agree with Mr. Brinton that the extensive use of dock cranes in European ports has been brought about through the impossibility of using floating cranes. For instance, Tilbury main dock at the mouth of the Thames, and many miles below any bridge, has 56 level-luffing cranes. The new Gladstone dock at Liverpool on the River Mersey, and below any bridges, is equipped with some 50 cranes; in addition to these there might also be mentioned the new docks at Dover, Bristol, as well as Bombay, Buenos Aires, and other places. Floating cranes are principally used in transporting cargo from ships' holds to lighters alongside, or vice versa, and are not suitable for unloading from ships' holds to dock. Their extensive use in New York is largely due to the fact that the docks there, which are mostly fairly old, are not of a construction that is suitable for accommodation of dock cranes.

The author agrees with Mr. Beyer that an important point with regard to cranes is the accessibility of parts likely to require repairs, lubrication, etc., also the safety of men who have to do such work. These considerations were not discussed in the paper on account of limitation of space that would be necessary to go into such matters fully. The author would state, however, that it is almost impossible to use stairways on any cargo cranes which necessarily are of the traveling type, and means of access to the crane have to be minimized as far as possible so as to make the under structure compact. Ladders with good hand railings on either side of them are, in the author's opinion, just as safe as stairways.

With regard to the safety hook, the type almost universally used in Europe is a hook which takes somewhat the form of a C, the lower portion of which, or the hook proper, is curved inward at this point so as to guide the sling should it tend to come out of the hook into the upper bend of the hook. This type of hook also has the advantage of not being likely to catch in any obstruction when it is being raised. Types of hooks which have movable guards are not only liable to get out of order but also cause delay in hooking on and off the slings.

[3] Consulting Engineer, President and Treasurer, Terminal Engineering Co., Inc., New York, N. Y. Mem. A.S.M.E.

# Bulk-Material Handling at Docks and Storage Plants

By A. F. Case,[1] Cleveland, Ohio

The scope of this paper does not include the handling of bulk commodities in small capacities, but rather the methods which have resulted in the vast production of today. In the discussion of this subject it is difficult to refrain from reviewing briefly the historical side of the development of modern equipment. The Great Lakes furnish a marvelous waterway for the transportation of the main bulk commodities, coal, ore, and limestone.

The source of coal lies adjacent to the southern end of this waterway, and the northern end extends into the greatest ore deposits in this part of the world. It is therefore logical that great fleets of ships have been constructed and equipment of high capacity has been developed to transport the immense tonnages required for modern consumption. Coal is the only material in this group used for both industrial and domestic purposes. The industrial demand in the districts of Pittsburgh, Youngstown, Cleveland, and Buffalo is served by rail.

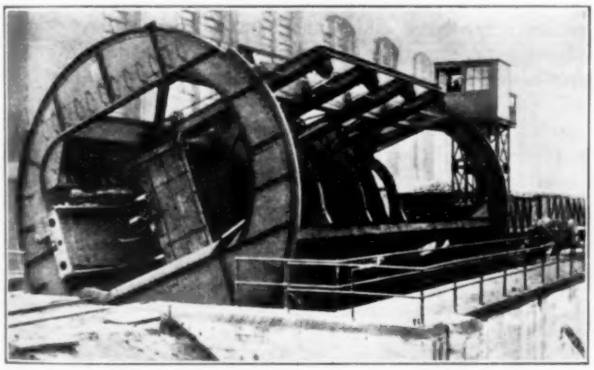

Fig. 1 Revolving Car Dumper

Detroit, Chicago, and Milwaukee use considerable industrial and domestic coal, but the upper lake region is the center of the vast domestic market, and the ports of Lake Superior are the destination of the large shipments from the lower lakes. This then is the background of our picture—coal cargoes from the lower to the upper lakes, and ore cargoes returning.

The first coal cargo was loaded into lake vessels in 1850 at Cleveland from the Mahoning valley by canal boats. This was first unloaded by hand and carried in wheelbarrows to a storage area on the dock, afterward being again handled by wheelbarrows on to the deck of the ship and dumped through the hatch into the boat. The boats at that time had capacities up to 150 to 250 tons and took about a day to load, using all the men as advantageously as possible.

It was not long before larger cargoes were required and mechanical handling methods were installed. This first took the form of revolving derricks designed to handle 1-ton tubs. These tubs were filled by hand and held by a catch which was tripped by pulling a cable attached to a latch. This was between 1875 and 1880. The size of these buckets was subsequently increased to 5 tons by 1892.

The use of revolving derricks was continued until 1890, when the first car dumper, the Lindsley, was placed in operation at the docks of the Cleveland, Canton & Southern Railway at Cleveland. At this time the car capacities were very much less than at present, ranging from 10 to 20 tons. There was a tendency, however, to use larger cars, and the old machines proved inadequate. The car-dumper art passed through several phases after Lang began to handle cars, and developments followed rapidly. In 1896 the first lifting car dumper was put in operation and was immediately successful. Modifications of this dumper are in use today.

The fundamental operation of these machines follows the practice of pushing the cars up an inclined approach by means of a mule car or larry and spotting on the car-dumper cradle, which is lifted to a predetermined height, when it is inverted, and the coal runs into a pan extending over the boat. This pan is contracted at the outer end, and a telescope chute is used to direct the coal into the boat. After discharging the coal the car is returned to its upright position and lowered by gravity to the starting point, where it is bumped out of the cradle by the next loaded car coming in. The empty car then runs down the discharge track into the empty storage yard.

Fig. 2 Coal-Loading Pier With Lifting Car Dumper, Revolving Car Dumper, and Conveyor

The modern machines have been greatly refined, but many of the original principles have been retained. All these original machines were steam operated. The first electrical operation applied to a car dumper for loading boats was at Baltimore in 1921 on the coal pier of the Western Maryland Railway Company. This was followed in 1926 by an electrically operated machine at Toledo, Ohio, on the Ohio Central Railroad Company dock.

This machine is the most modern of its type and has several interesting features. It is the first electrical car dumper of the lifting type installed on the Great Lakes. The operation of the mule and cradle motions employs the Ward Leonard principle of generator field control, and the cradle is over-counterbalanced so that the amount of power required is about the same to raise the loaded car as to lower the empty car after dumping.

The constantly increasing size of cars and capacity demands have required the special features described. The Toledo

[1] Manager, Ore and Coal Division, Wellman-Seaver-Morgan Co.

Presented at the First National Meeting of the A.S.M.E. Materials Handling Division, Philadelphia, Pa., April 23 and 24, 1928.

machine is designed to handle forty 120-ton cars per hour. These cars when empty weigh 41 tons, and loaded, 160 net tons. The problem of handling cars of this capacity was solved by applying counterweights in such a manner that the effort acts directly on the cradle to balance part of its deadweight when lifting, and also on the drums which operate the cradle-hoist system. The horsepower is thus reduced to about 900 for the cradle hoist as compared to about 1700 hp., which would be required to obtain the same capacity by previous methods of counterweighting. The mule-haulage function of this machine also requires but 900 hp. The generator field control also effects considerable saving in current consumption. In fact, the total current per ton of coal handled in 70-ton cars during the season of 1927 was only 0.24 kw-hr., and this would be considerably reduced if larger-capacity cars were handled.

Coal handling on the Great Lakes is an industry in itself, but enormous quantities are also handled at Atlantic seaports. Norfolk, Va., is probably the largest of these. The Norfolk & Western, Chesapeake & Ohio, and Virginian have extensive

Fig. 3 Electric 80-Ton Coal Transfer Car

facilities. These differ greatly from the plants on Great Lakes ports, employing simple turnover car dumpers which empty the material into transfer cars of 100 to 120 tons capacity. These cars are elevated to tracks on the top of huge pier structures with pockets and chutes for discharging into ships. The cars are self-propelled and provided with discharge gates at the bottom through which the coal passes into the pier pockets.

On the new pier of the Virginian Railway the pier structure differs in that movable loading towers carry the pockets into which the transfer cars discharge, and steel conveyors on booms extending over the hatches of the ships carry the coal to a telescope through which it passes into the ship's hold.

Baltimore is another port of importance and probably possesses a greater variety of coal-handling equipment than any other Atlantic port. The Baltimore & Ohio equipment at Curtis Bay consists of two turnover car dumpers which discharge the contents of road cars on to belt conveyors, which serve movable loading towers provided with shuttle conveyors carried on adjustable booms which may be extended to either side of the pier for loading purposes. The Pennsylvania Railroad at Canton is equipped with a single car dumper which discharges into small cable cars traveling on an elevated trestle extending the full length of the pier. These cars are automatically tripped and their load is discharged into the hoppers of movable loading towers similar to those on the Virginian pier.

At Port Covington the Western Maryland Railway has a 100-ton electrically operated lifting car dumper on the pier in a stationary position and arranged to load directly into boats. Coal may also be diverted through a bypass chute arrangement and conveyors to a stationary loading tower on the opposite side of the pier.

Recently a new facility has been added by the Western Maryland to their plant, noteworthy in that it represents a radical departure from generally accepted methods of handling coal from cars to boats. Cars are introduced into the dumper by the standard mule-car method up an approach incline, and after being dumped they run down a gravity track to a kickback and into a storage yard. This method is common to practically all loading plants.

The car dumper in this case differs from all others by being of the revolving type; that is, it consists of a barrel structure which holds the car and turns about its own axis to dump. On account of the characteristics of this motion it is possible to control the discharge of coal into the hopper beneath the dumper so that there is practically no breakage. The material is removed from the hopper by a steel apron feeder which discharges on to a 60-in. belt conveyor. This carries it to the stationary loading tower, where it is taken by the boom conveyor and discharged into the ship. This is the first modern plant to employ the revolving car dumper, although the machine has been very extensively used in power plants and materials-handling plants remote from waterways. The cradle power requirements are very low, only 125 hp. being required to handle forty-five 120-ton cars per hour, and the power may be either alternating or direct current.

This construction included in this latest plant of the Western Maryland Railway is the first step in a revolutionary revision of modern coal-loading methods. The ideal plant consists of mule haulage, a revolving car dumper, and a loading tower with a high-capacity conveyor carried by boom extending over the ship's hatch, and a telescopic chute to conduct the coal into the hold.

Such a plant possesses advantages present in no other arrangement—low initial cost, low operating cost, practical elimination of breakage, low current consumption, low maintenance, absence of massive structures, and other features less essential. These

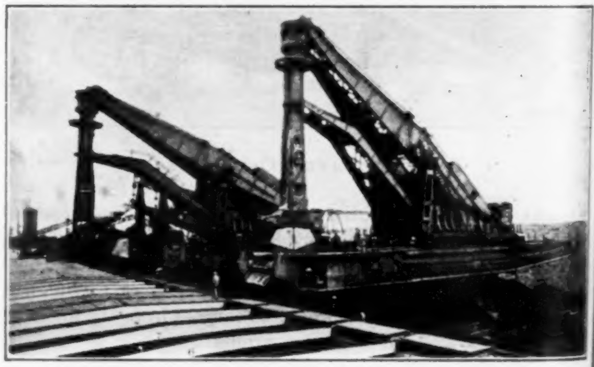

Fig. 4 Two 15-Ton Hulett Ore Unloaders

advantages are so superior that the Pennsylvania Railroad, after completely investigating all important coal-handling plants to determine the best facilities for their new coal pier at South Philadelphia, selected the revolving car-dumper equipment just described.

There are several other important coal-loading ports on the Atlantic Coast, nearly all of which are provided with the old type of lifting car dumpers. So much for the loading of coal.

The problem of unloading coal from boats on the upper Great Lakes region centers about Duluth and Chicago, where unloading bridges equipped with man trolleys handling rope-suspended grab buckets are extensively used. These bridges span large coal-storage areas which are stocked during the navigation season to supply winter demands. The coal from these storages is

handled by the bridges into screening plants, where it is screened and classified for domestic distribution.

At the plant of the Canadian Pacific Railway at Fort William, Ontario, the coal is taken from the boats by Hulett unloaders and transferred back into storage by bridges. The Hulett machine is primarily an ore unloader and will be described later.

The handling of iron ore from the Lake Superior region dates from 1854. Up to that time the total shipment of ore had come from the Marquette range, and the total tonnage was approximately 3000 tons in that year. The shipment of ore continued from the Marquette range until 1877, when 10,400 tons of ore was shipped from the Menominee range. The total yearly tonnage from that time to the present has increased by leaps and bounds, until the figure at present is between 65 and 70 million tons per season.

The original handling of this ore was by hand, as in the case of coal, but as the tonnage increased it was necessary to provide mechanical-handling methods which followed closely in the footsteps of the development in the coal-handling industry.

At present there are only two accepted methods of removing ore from ships, one being the rope-operated grab bucket handled by a suitable bridge or tower structures, and the other the Hulett unloader.

As previously stated, the traffic of coal and ore involves the shipment of coal from the lower lake ports to the upper lakes, and return cargoes of ore are brought down in the same ships. The

Fig. 5 Movable Car Dumper

loading of ore at the upper lake region is essentially different from the loading of coal. At the ore ports of two harbors, Duluth, and Superior, the ore is loaded at the mines into specially constructed hopper cars which are provided with drop-bottom doors. Trains of these cars are brought down to the loading pier, where the car doors are opened and the ore is discharged into pockets in the pier which are provided with chutes through which the ore is discharged into the hold of the vessel. On account of the multiplicity of chutes leading from these pockets, it is possible to load a vessel in a very short time as this work is accomplished entirely by gravity. Inasmuch as the breakage is not a factor in the handling or ore, this method is ideal for transferring from cars to boats.

The removal of the ore from the boats, however, is quite an-

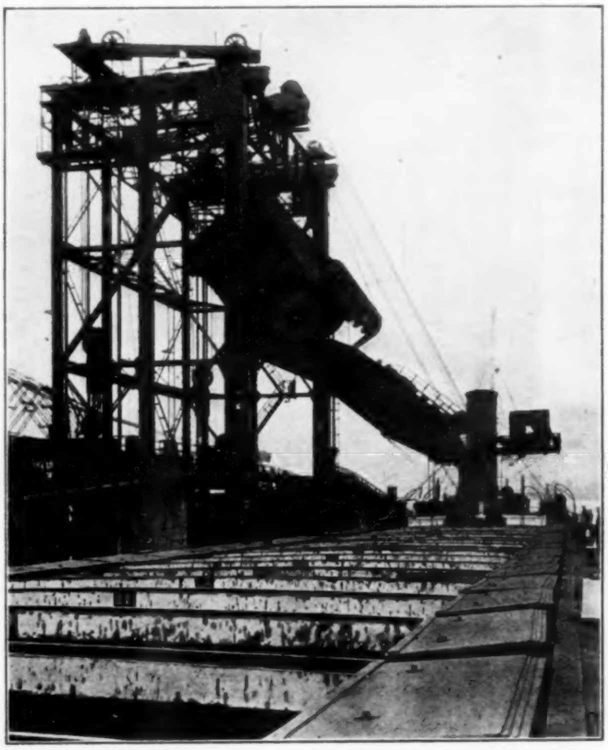

Fig. 6 Lifting Car Dumper, 120 Tons Capacity

other problem. This has been successfully accomplished by means of grab buckets operated by unloading bridges and also by small unloading towers which have been called "fast" plants. These in the majority of cases are used for unloading boats for direct shipment. When storage of ore is required it has been common practice to use unloading bridges for this purpose, but in the majority of large capacity plants the Hulett unloader has been adopted for the unloading operation.

The Hulett unloader was first built in 1898, and at that time was operated by hydraulic power in the main functions, the hydraulic power being supplied by a steam accumulator carried on the walking beam, and these machines had been in constant operation up to 1926, when they were dismantled.

This machine consists essentially of a traveling gantry framework forming a support for a trolley which travels transversely to the dock. This trolley in turn supports a walking beam, which in the forward position of the trolley extends over the boat. From the outer end of this walking beam a stiff leg is suspended, at the bottom end of which is the bucket-operating mechanism and the bucket shells. The descent of the bucket into the boat is by gravity, the forward end of the walking beam being slightly heavier than the rear end. The walking beam is raised by a mechanism at the back end of the beam which is provided with ropes passing around sheaves at the rear end of the trolley and anchored to the back end of the beam. By slacking off these ropes the bucket is allowed to descend into the boat. The opera-

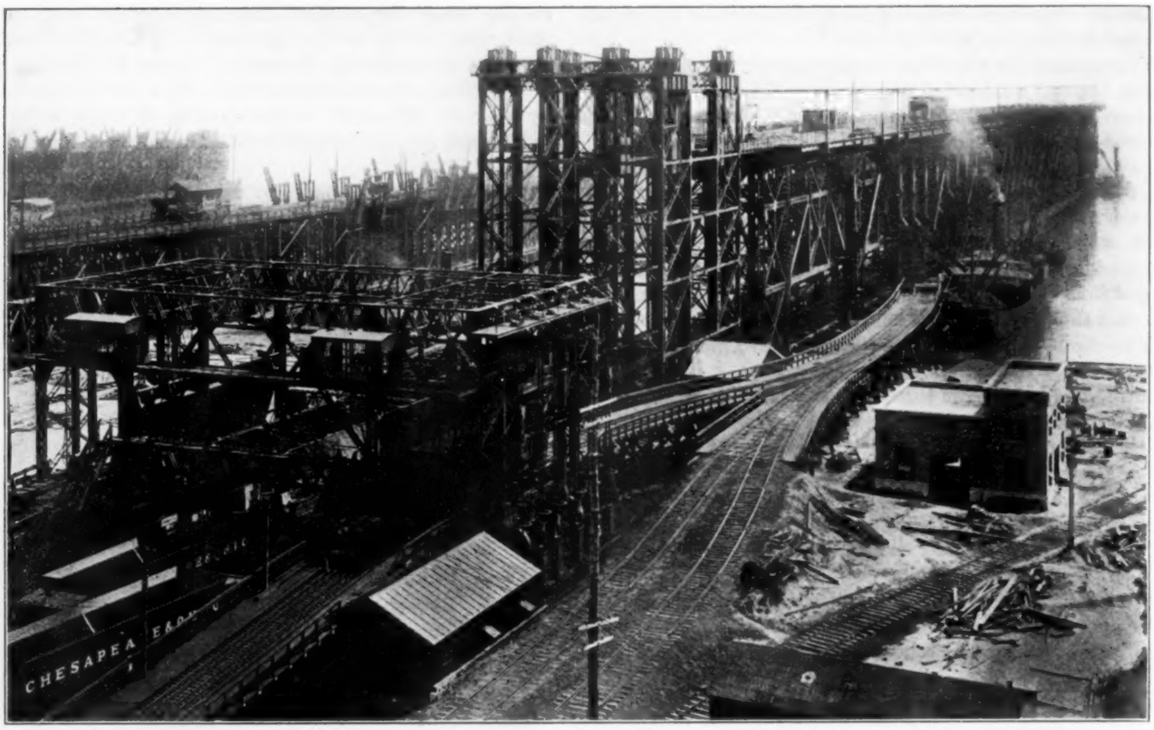

Fig. 7 Extensive Car-Handling Facilities of the Chesapeake & Ohio

Fig. 8 Five-Ton Man-Trolley Ore-Handling Bridge

tor for controlling the motions of the bucket, the walking beam and the trolley, and in some cases the movement of the total machine along the dock is in a station just above the bucket in the bucket leg, and he travels with the bucket into the hold of the boat, where he can see all of the operations of the bucket and accurately control them.

The latest machines of this type have bucket capacities of 17 tons, and in some cases the digging power of the bucket will take up 18 or 20 tons. In operation the bucket is lowered into the hold of the boat and closed in the ore. The bucket is then elevated, and the trolley runs back to a point just back of the front gantry leg, where a receiving hopper is provided into which the bucket dumps. The bucket trolley is then moved forward, the bucket lowered into the hold of the boat, and another bucket load is taken up. During the interval that the bucket is getting its second load the receiving hopper is discharged into a larry which travels on an auxiliary track on the underside of the gantry framework. This larry is usually provided with scales and is arranged so that it can be traveled over any of the tracks beneath the gantry span and the ore discharged into the cars after being weighed. In case it is desired to store this ore the larry travels back of the rear runway and discharges its contents into a temporary pile where it can be picked up by a storage bridge and rehandled into the main storage area.

In addition to the functions described, the bucket leg is also capable of swiveling about a vertical axis so that the reach of the bucket is available for cleaning up ore between the hatches. In this way over 95 per cent of the ore cargo can be taken out of a boat without the use of any hand shoveling. This is much in excess of the possibility of any rope-suspended grab-bucket machine.

Another point of advantage in the Hulett unloader is the fact that the forward end of the walking beam is just enough heavier than the back end to give the bucket proper digging power in

Fig. 9 Gantry Handling Load Back to Storage

the boat. This is about 10,000 lb., while the rope-suspended buckets of this capacity would have a weight of from 30,000 to 35,000 lb. This results in the case of the Hulett unloader in a very much smaller initial load being applied to the tank top of the boat, and consequently the boat damage is very materially decreased. Also on account of the fact that the bucket is accurately guided through the hatch there is no possibility of interference with the upper structure of the boat around the hatches.

The structure of these machines is very heavy, and the machines are more or less complicated. The results from their operation, however, are fully justified from the fact that while the mass is great the moving load in lifting the bucket is not very much greater than the ore contained in the bucket, and the movements are so deliberate without the usual shock found in other types of machines that the maintenance cost is very low. The capacity, however, is almost double that obtainable by any other type of machine. There is a handling record that was made by eight 15-ton machines at Ashtabula, where seven boats having a total capacity of 70,000 tons were unloaded in 22 hours actual working time, and another record was made in June, 1926, where five 17-ton machines at Conneaut, Ohio, unloaded 11,300 tons in two hours and twenty minutes from the steamer *James A. Farrell*. This reduced to unity makes a handling record of 970 tons per hour for each machine including all of the clean-up time. There have been instances where these 17-ton machines have unloaded over 1200 tons per hour each.

There are over 50 machines of this type in operation on the Great Lakes, and while these are not all of the size described, they represent the progressive stages of the development leading up to the present machine.

After the ore has been unloaded from the vessels at the various plants it is loaded either directly into cars or from storage into cars, and these cars are transported to the furnace plants where the ore is used. The removal of ore from these cars is usually accomplished by means of our car dumpers which are divided into two classes, the movable class and the stationary class.

With the movable type of dumper the ore is dumped direct from the car into the storage pile, usually dumping over a retaining wall between the car dumper and the storage. These movable car dumpers are not greatly different from the stationary type except that they are mounted on trucks and the machine is provided with inclined approaches at either end. Cars are introduced into these machines by means of a locomotive, and after the car has been dumped it is pushed out of the machine by the next incoming car and the empty runs out on the discharge track, to be subsequently picked up in a train by means of a switching locomotive. These machines are of course electrically operated and travel lengthwise to the storage yard so that they can be spotted opposite the point where it is desired to store the particular kind of ore which is being handled.

When the stationary type of dumper is used, the ore is usually dumped into a transfer car, which after receiving its load travels over a trestle system and discharges from the trestle into the storage yard or into furnace bins. The fundamental principle of these car dumpers is about the same in all cases.

After the ore has been discharged either by the movable car dumper or by transfer cars into the storage space, it is rehandled by means of bucket-handling bridges into the main storage pile and again rehandled into furnace bins when required or is rehandled for the purpose of shipment when stored in temporary areas.

## Discussion

Ed. F. Mullin.[2] One point that the author brought out was that the capacity of the rotary type of car dumper was 45 cars per hour. That would lead one to believe that he must have a large capacity to consider a dump of that type, but that is not so. We know of several installations where a comparatively low rate of capacity has warranted the rotary dump because it is an economical installation in the first place and it dumps very quickly. In one installation that handles about 2000 tons a day they will dump all that coal in about three hours, whereas by the old method with ordinary track hoppers it required from 12 to 20 negroes shoveling 10 or 12 hours a day. The horsepower for operating the rotary-type dump of course is very low.

[2] Link Belt Co., Nicetown, Philadelphia, Pa.

# Fundamental Principles in Materials Handling

By HAROLD VINTON COES,[1] NEW YORK, N. Y.

THERE comes a time in almost every industry sooner or later when the economic forces shift with relation to each other and produce results for better or for worse. When this situation arises or is foreseen, emphasis must then be placed on the analysis of those factors that are causing the difficulties which confront us. In any given industry this may mean a readjustment of the capital structure; of methods of distribution; of extracting, processing, or fabricating; of the types, utilization, and compensation of labor; of equipment and methods; of the overhead structure and of the personnel of the organization.

I think it may be taken as axiomatic, although unfortunately not yet so recognized by industry or executives as a whole, that group understanding, group cooperation, and group statistics are now vital to the successful conduct of any industry and of the several entities in that group. No intelligent mariner would now think of navigating a ship without adequate data, technical equipment, and authentic charts, yet we in industry have to navigate altogether too much on the yet inadequately charted seas of business.

Again it can be taken as axiomatic that no industry can long continue on a price basis alone or without adequate profits.

There is an economic law that the price of any given commodity tends to approach its cost of production, but it should be noted that "cost of production" as used in this law includes all legitimate costs of extracting, processing, production, and distribution, and a reasonable profit as well.

It should be noted in passing that profitless prosperity is not confined to any one industry, but is prevalent in entirely too many at the present time. This problem is engaging the attention of some of the keenest minds in the country in all lines of business.

## Mechanization of Industry

The discussion, however, will be limited to merely one phase, the mechanization of those operations still performed by hand labor that come under the category of materials handling. The author will endeavor to sketch briefly some of the fundamental principles of materials handling, which in their broadest aspects can be and should be recognized and applied to any industry where a materials-handling program is to be worked out.

## Surplus Labor in Industry

There is a question that naturally will arise in many of your minds, namely, "Is this going to reduce the number of operatives per industry or per unit of industry?" Frankly, yes, and it should if we are to continue to raise our standard of living; and by that I mean not only greater wealth per capita but more leisure per capita. For I am not one of those who believe it is necessarily important for one to work laboriously six days a week to keep one's soul from becoming claimed by the devil.

We have several instances of this reduction of personnel per unit of product. For instance, the *Iron Age* in its issue of July 28, 1927, made reference to this factor in the automobile industry as follows: "While one of the leading automobile plants required 17,000 workers in 1916 to turn out 650 cars a day, today the present force is approximately 15,000 and this force has no difficulty in producing 1500 cars a day. Worked out another way this means that in 1916 it took 26 man-days for each car against 10 man-days under present conditions. Installation of machinery for cutting down both time and labor, employment of mechanics and department heads specially trained in the work, proper routing of manufacturing operations through the plant, modern equipment for materials handling, and more exact methods of manufacture through the use of more accurate machines, all taken together account for this great improvement in performance."

Mr. C. S. Ching, president of the American Management Association, in a recent address before that association comments on this situation, in so far as the tire industry is concerned, as follows. "It has frequently been said that this industry was among those which had so greatly expanded its plant that it was now unable to operate to capacity. Now the truth of the matter is that tire production in the past five or six years has been far greater than during the war period, or for that matter in the two-year business boom following the war. If we were producing tires at the same rate per employee and required the same plant equipment for each tire manufactured as formerly, the present number of employees and plant equipment would have to be more than doubled."

## Absorption of Surplus Labor

The next question is, "What is to become of this labor that is released?" Let us ask ourselves the question, "What became of the labor released by previous mechanizations in agriculture, industry, mining, etc. The reaper and harvester released labor, and so did the sewing machine, the cotton gin, the typewriter, gigantic ore excavators, etc. This labor was temporarily thrown out of adjustment, but ultimately it flowed into new industries that were created after this labor was made available. Where did the labor come from for the automobile industry, the radio industry? Where is the labor coming from for the rapidly developing aviation industry, with all the collateral developments that will certainly accompany it? Why, it will have to come, since our immigration laws are in effect a protective tariff, from the labor released by the intensive mechanization of our existing industries.

Who is so bold as to state that no new industries will be born or that man's wants are completely satisfied? Yes, we shall need this labor. It is unfortunate that we do not have such a perfect adjustment of supply and demand and control of our production and distribution mechanisms that we can immediately absorb this labor as it is released. That it always has been ultimately absorbed is a reasonable guarantee that it all will ultimately be absorbed, even though there are periods of readjustment that are difficult to deal with.

So let us proceed with the firm belief that what we are doing in intensive mechanization in our present industries is for the greatest good of the greatest number.

The problem then, stated in its broadest terms, is simply this: We must reduce our unskilled workers per industry to the veriest minimum by all the aids and skill at our command, and at the same time increase the productivity of the balance to the maximum both as to production per dollar of payroll and as to individual earnings on purchasing power.

## Cost of Handling Materials

The public is slowly beginning to appreciate the fact that the cost of living is intimately related to the cost of production and of distribution, and that one of the big factors in the cost of pro-

[1] Ford, Bacon & Davis, Inc. Past Vice-President, A.S.M.E.

Presented at the First National Meeting of the A.S.M.E. Materials Handling Division, Philadelphia, Pa., April 23 and 24, 1928.

duction and of distribution is the enormous toll due to handling, picking up and putting down, and rehandling the materials of agriculture and industry. Think of it! a manufacturer of agricultural implements in a modern plant estimated that he had to handle 108 tons of materials for every ton of finished product f.o.b. his plant!

Before the war the railroads normally handled about 1,000,000,000 tons of miscellaneous freight annually, and the seaport terminals handled about half as much more as package freight, or 500,000,000 tons. It has been estimated that adequate materials-handling devices could handle this tonnage at a reduction in cost of $400,000,000 annually. If this saving could be distributed equally per family it would represent an annual saving of $16 for every family in the United States. What this saving might be if the enormous tonnage handled annually in industrial plants could be similarly reduced in cost is problematical; that it is several times $16 per family per year is unquestionable. I have estimated it at $400 per family per year.

A survey made for a leading trade paper a year or two ago indicated that the materials-handling labor cost to American industry was 22 per cent of the total annual payroll of the American manufacturing industries in 1923, which was $14,017,107,000; and 22 per cent of this amounted to $3,084,000,000.

Eugene B. Clark estimates that manufacturers in this country pay for moving materials within their plants 80 per cent of what they pay for freight, express, and parcel post annually.

It took decades and armies of men, thousands of whom perished on the job, to build the pyramids or the ancient South American structures; yet we build structures of similar dimensions and of infinitely greater complexity today with hundreds instead of thousands; in a year or two, instead of decades. How? By perfection of labor-saving devices and organization.

It can be taken as axiomatic that nothing is where you want it or where it must be finally placed in so far as raw materials are concerned, and usually in so far as finished goods are concerned, so that the pyramiding of tolls on account of the handling of the rawest of raw materials to the most finished of finished products is enormous.

### Human Wants

Now the starting points of the supply of human demands are the raw materials of nature in the animal, vegetable, and mineral kingdoms, in the air or on or under the earth's surface or the waters thereof.

We now have the rough dimensions of our problem of supply, what are the factors in it, economic, psychological, political, and engineering. It is necessary to determine the economics of the situation in order to decide as to what investment is justified. Frequently the opposition in the change from the old methods to the new devices is psychological owing to a misconception of the effect of the program on an individual or a group, or it may be because of plant or labor-union politics, and again it may come from lack of appreciation or from misconception.

### Some Important Facts in Materials Handling

Suppose we set down the known facts such as will guide us properly to a correct solution of the materials-handling problem and the right use of materials-handling devices.

*New-Plant Operation.* In a new industrial undertaking materials handling is an important factor in determining

(*a*) Plant location
(*b*) Plant layout, present and future
(*c*) Departmental layouts and sequences
(*d*) Production equipment, layouts, and sequences
(*e*) Plant output
(*f*) Operating costs per unit of product.

Obviously for a minimum investment and lowest cost of operation consistent with the present state of the art the new plant should be so located as to take full advantage of all the natural advantages available. The materials-handling methods and devices should be sufficiently worked out at the time the plant is designed so as to make them an integral part of the design.

An industrial plant is not a box in which you dump in the three "m's," money, men, material, shake them around, and precipitate finished products. It takes brains, knowledge, and experience to properly design, build, equip, and operate an industrial plant. Why therefore perpetually handicap the business by embodying in unyielding bricks, mortar, steel, and concrete at the start, conditions which make it economically impossible properly to install and operate adequate materials handling equipment? Yet it is being done every day.

*Existing Plant.* In an existing plant the proper selection of adequate materials handling equipment will

(*a*) Increase the output
(*b*) Lower the cost
(*c*) Facilitate administration and management.

### Important Principles

Every element of materials-handling equipment should be selected not only to perform the work at present but in most instances, except in specifically isolated cases, to fit into the program conceived for the ultimate plant or the rehabilitation of the existing plant.

Eliminate all unnecessary handling operations; perform all necessary handling operations by gravity wherever economically possible. This statement seems almost axiomatic. Yet it is no uncommon thing to go into a plant and see laborers performing operations that are totally unnecessary, many of which could be eliminated at a very moderate expense, and some of which could be eliminated by the application of brains and planning alone.

Choose the methods and equipment for performing the necessary handling operations that will result in the lowest cost. You will find very often that your first solution of the problem does not result in the lowest cost when compared with your subsequent solution. It is therefore decidedly advisable to compare the cost per unit handled obtained from several practical methods of solving the problem, and then select the methods and equipment that will result in the lowest cost.

Choose standard proved and tried equipment wherever possible. Few businesses can afford to divert the efforts of the organization or the facilities of the plant to experimenting to produce a new materials-handling device unless the nature of the product and the processes or the intermediate operations are such as to render it advisable to design devices to suit conditions that equipment now on the market cannot successfully meet. Otherwise it is decidedly better to endeavor to solve the problem by the selection of known and proved equipment.

In a new plant the materials-handling devices and equipment should for lowest investment costs be an integral part of the plant in many instances. In designing a new plant and in selecting a site for one every natural advantage that can be called to aid, either in eliminating the amount of material that has to be handled or the length of the travel, should be utilized. Frequently gravity can be made to do a large portion of the work, in which case slides, chutes, rollways, bins, and the like usually can be made an integral part of the structure.

Provide for flexibility so that a failure of any of the materials-handling devices or equipment will not shut down the plant. In any materials-handling system the equipment required should be so arranged and selected as to provide flexibility in operation, so that production is not tied up by the failure of any element or unit of the materials-handling equipment.

The path of the material should be as direct as possible from the receiving point through processing steps without rehandling and with the minimum retrogressions in the whole line of travel. Before arranging for any system of shop or plant transportation a study should be made to see if the departments can be so rearranged as to permit minimum travel in logical sequence with the minimum of retrogressive movements. In other words, do not transport materials any farther than is absolutely necessary. Frequently a study of the departments, their relationships, and the sequence of operations or processes will show that a rearrangement can be made to advantage.

The investment must be justified by the return. It stands to reason that the return on the investment should be such as to justify it. Many of the progressive companies have a fixed policy that provides for the scrapping of any piece of equipment or process whenever it can be shown that the proposed piece of equipment or process can earn 20 to 25 per cent. Obviously this is good business.

The return should provide for adequate fixed charges. In order to show the proper return on the investment, provision should be made in calculating fixed charges for interest, taxes, depreciation, insurance, obsolescence, etc.

### What Materials-Handling Programs Will Accomplish

Properly selected and installed handling equipment will

1. Permit transferring to the capital account of the portion of overhead that is composed of indirect labor
2. Reduce the manufacturing cycle
3. Reduce the process inventory
4. Speed up, coordinate, and stabilize production
5. Facilitate the obtaining of accounting and production data
6. Substitute automatic mechanical scheduling for the former complicated expensive schedule and production systems
7. Govern the layout of new plants and improve the performance in existing plants.

W. F. Merrill, president of the Lamson Company, makes this statement: "The usual concept of industrial transportation problems has been confined to the man-saving, the labor-saving functions. True it is that this one element alone has already effected such great economics as amply to justify the time and thought spent on its development, but without minimizing the self-evident values of this one economic function, the broad principle behind the movement still seems to be but imperfectly understood and insufficiently applied to use.

"The industry of the future will in my opinion devote as much time to a scientific coordination of its manufacturing and materials-handling elements in their relation to production flow as it now denotes to the invention, design, and manufacture of its product and the machines that make it.

"Synchronized material movement and the grouping of production processes are important principles in the proper working out of the transport science in production. Systems of conveying properly applied may enhance production 10, 25, or even 50 per cent with the same man power and machine equipment.

"In the travel of material through the processing route it is on the average worked on less than one-third and often but one-sixth of the time. Work in process is thus often the graveyard of profits."

### Some Rules for Securing Materials-Handling Economies

Mr. McLain of the General Electric Company sets up the following rough list of instances where economies may be hoped for in the use of machinery instead of men, where said men are unaided by any mechanical device:

1. Where three or four men are working together on one job for a couple of hours at a time, even though the work is not performed more than three or four times a week
2. Whenever a man has to lift anything from his feet to a point above his head
3. Whenever a man has to lift more than 50 lb. from his feet to his shoulders
4. Whenever a man has to lift more than 100 lb. from his feet to his waist
5. Whenever a man has to lift more than 150 lb. from his feet to his knees
6. Whenever a man has to stand in one place steadily moving material for over 30 min.
7. Whenever a man has to move material sidewise more than 6 ft., that is, two steps
8. Whenever a man or a group of men, although moving around in a small radius, has to move more than 10 tons of material per hour.

### Selection of Equipment

One of the things that is the cause of much subsequent economic woe in the selection of materials-handling equipment for a specific set of conditions is confusion between service and mere mehcanical or electrical performance. A piece of equipment may be mechanically perfect, yet its selection for a given set of conditions be an economic crime because it is not designed to function so as to meet all of the conditions imposed and therefore operates at a loss.

The equipment companies are somewhat to blame for this situation. Rarely do their sales representatives know anything about the equipment of other manufacturers unless they are directly competing along absolutely parallel lines. It is my firm belief that the equipment manufacturer in the long run would have more friends and build up a more substantial good will if they would refuse orders as well as take them; in other words, if they would insist on selling service and serviceability rather than pieces of equipment.

### Comparative Costs

There is a serious lack of fundamental data as to costs of operation and a confusion of these costs. The Materials Handling Division of the A.S.M.E. is endeavoring to act in a coordinating and collecting capacity with respect to this phase of materials handling, and has devised and set up standards and formulas for comparing correctly dissimilar methods; this is nothing more than the application of mathematics to economics.

### Plant Transportation

We sometimes fail to realize what transportation costs. Why? Because some accountant once said that it was an overhead charge, and therefore it is buried in that sink hole labeled "overhead." Manufacturers can tell you exactly what their raw materials cost, how much they use, what their losses are, etc., and similarly with labor; and yet very few have set up the machinery to know what their shop transportation actually costs them.

When you once take the transportation problem apart, study the equipment, methods, rolling stock, right of way, dispatching, commodities handled, and assess the costs properly, you will usually get a shock.

There is hardly an industrial plant where costs cannot be reduced, without necessarily reducing wages, and one of the little gold mines in which I recommend you to delve is shop transporta-

tion in its broadest sense. You will frequently find that the outside consultant can bring to bear a wealth of experience in varied lines that will materially assist you to a right solution of the problem and the real dimensions of the justifiable expenditure.

There are many intangible benefits that directly accrue from the correct solution of shop-transportation problems besides the direct saving in labor. These are:

1 Reduced production space, permitting increased production in the same place
2 Lowering the cycle of goods in process
3 Reduction of inventories
4 Steadying of production and enhancing the control, resulting in better deliveries, increased sales, and more efficient purchasing
5 Speeding up of labor, since machines and men are not kept waiting for material
6 Better cost and production records.

Occasionally one meets a reactionary, who immediately objects to materials-handling methods because it adds complication to his plant. Complication! If you could see the complicated maneuvers some of them go through to obtain production, you would immediately say, "Yes, we'll resort to the paradox of adding complexity to complexity to attain simplicity." That may be too deep for some of the reactionaries.

### Reliability of Equipment

Tried and proved materials-handling equipment produced by reliable manufacturers is just as dependable in performance, and in freedom from breakdown, and just as economical in operation and maintenance as the productive equipment proper. Few charges to the contrary can be sustained. If breakdowns occur, if maintenance is high, it is owing to a lack of care, to improper selection of the units in the first place, and to overloading the equipment.

### General Situation in the Coal Industry

The general situation in the coal industry is no different from that of other industries. You have a given fixed investment, a given amount of fixed charges. If you can reduce your processing cycle by reducing the total time it takes to get out a ton of marketable material and get it on the market, you have increased the turnover of your fixed assets. You may have increased your processing indirect expense by the amount of additional fixed charges on materials-handling equipment, but you have decreased your direct expense, and the net result is a reduction in cost per ton of marketable material.

For example, an attempt was made to market coal from a vein in a drift mine by simply dumping the raw coal into cars. The coal was so dirty, however, as to be practically unusable and unsalable. A modern tipple with elevating, conveying, crushing, screening, and washing systems was installed. While it added much to the cost of handling, yet it so improved the product that it found a market at satisfactory prices. Now to have cleaned and graded this coal by hand, even in the low-cost-labor district where this mine was located, would have been prohibitive.

I am unaware of the average labor cost per ton of mined coal, but I believe that 65 to 70 per cent of the total cost f.o.b. the mine would be a fair assumption and come reasonably close to the facts.

The Carnegie Institute of Technology in its Bulletin No. 17, "Mechanical Loading in Coal Mines," shows that average savings of 37 per cent can be made by the use of loading machinery. This average is obtained from a range of 49 per cent, when a high wage scale is used, to 22 per cent for a low wage scale. For scoopers and conveyors, the loading in thin beds, average savings of 35 per cent can be made. This was obtained from a range of 40.3 per cent in high-wage-scale districts and 23.4 per cent in the low-wage-scale districts.

At my request W. K. Liggett submitted four typical examples of labor cost per ton of coal produced at the mines (Table 1).

TABLE 1

| Operation | Example 1. $6^1/_2$-ft. vein, drift mine, Pennsylvania, non-union | Example 2. 4-ft. vein, drift mine, West Virginia non-union | Example 3. 5-ft. vein, shaft mine, Indiana, union | Example 4. 6-ft. vein, shaft mine, Illinois, union |
|---|---|---|---|---|
| Cutting | \$0.12 | \$0.11 | \$0.14 | \$0.14 |
| Loading | 0.41 | 0.48 | 0.81 | 0.80 |
| Miscellaneous day labor underground | 0.13 | 0.16 | 0.30 | 0.30 |
| Miscellaneous day labor above ground | 0.12 | 0.15 | 0.24 | 0.24 |
| Total | \$0.78 | \$0.90 | \$1.49 | \$1.48 |

It will be noticed that the loading cost in the non-union mines was $52^1/_2$ per cent and $53^1/_2$ per cent, and in the union mines was $54^1/_2$ per cent and 54 per cent, so that regardless of the wage scale the loading cost was better than 50 per cent of the total cost in each case. This portion of the processing then would seem to indicate an opportunity to apply mechanical appliances and intensive materials handling, for if this cost could be lowered 40 to 50 per cent it would effect a material reduction in the total labor cost, and hence in the total cost of production. I have cited these cases simply as indicative of the mode of attack used in industry when confronted with similar problems.

Mined coal handled with locomotive cranes, for example, shows an average cost of 18 per cent of the hand operations, after including liberal charges for maintenance, fixed charges, and operating costs.

Economy in moving material, then, is secured as a rule by not moving it by hand.

The cost of production of most products is almost directly proportional to the cost of handling the various materials, direct and indirect, used in the process, be it extraction or manufacturing industry.

Material in traveling through the processing route is worked on (i.e., direct labor operations) on the average from 30 to 40 per cent of the possible time, and frequently only 15 to 20 per cent, so that it behooves us to analyze our work-in-process accounts and see what is buried in them and what can be done to increase the turnover. Proper materials-handling programs and equipment are usually the answer.

# A Materials-Handling and Transport Organization

By C. A. Fike,[1] East Pittsburgh, Pa.

*The paper outlines briefly the organization which has in charge the materials-handling activities of the Westinghouse Elec. & Mfg. Co. at East Pittsburgh. It describes the equipment used, the operation of it, and the methods of its control, and several of the wage-incentive plans which are used in the payment of the employees of the Plant Transportation Department. The paper concludes with a statement of some of the economies resulting from the organization described.*

Materials-handling activities are considered of sufficient importance in the Westinghouse Elec. & Mfg. Co. to justify the existence of a separate department whose responsibility it is to transport all material within the works in the most efficient and economical manner. It is the purpose of this paper to outline briefly this organization, its operation, method of control, and several of the incentive payment plans used with some of the economies resulting from them.

The combination of the various means of material transport, such as trucks, cranes, elevators, etc. into one department makes possible quicker and more efficient service, for in most cases material is handled by more than the one transportation means before it reaches the shipping floor in its finished state. Thus, with the various units closely linked together and under one control, no time is lost in transfer and the proper method is used at the right time. This in itself is an argument in favor of centralized control of all material-transportation activities, for in considering materials-handling problems, no general engineering formula can be applied, but all available means of transportation, and their relation to one another, must be considered before the best solution can be reached.

## Organization and Equipment

The materials-handling department at the East Pittsburgh Works of the Westinghouse Elec. & Mfg. Co. is called the Plant Transportation Department. This name in itself pretty well describes the function of the department. Materials-handling may be divided broadly into two general classes: first, that within the individual manufacturing section where it may be from machine to machine, or from operation to operation, so that the time consumed, or a greater part of it, is usually included in the manufacturing operation; and second, the movement from section to section, whether of raw material, finished, or semi-finished apparatus. It is mostly with the latter division that the Plant Transportation Department deals.

An idea of the transportation problems at the East Pittsburgh plant can be secured when the size of the plant is considered. The longest distance for an interdepartment haul is about one and one-half miles with an average haul of about one-half mile. Most of the buildings are two story, but as an exception there is one nine-story building and three four-story buildings, making a total manufacturing floor area of more than 4,000,000 sq. ft. As can be seen, both horizontal and vertical transportation must be considered.

In addition to the main works, there are three outlying departments at distances ranging from one-half to two miles which must receive the equivalent of the interdepartment service, notwithstanding the fact that material must be handled by two different transportation mediums—motor truck and industrial truck. Also, service must be maintained with the other Westinghouse plants in the Pittsburgh district located at Pittsburgh, Homewood, Wilmerding, and Trafford. Irregular but frequent truck and taxi service must be furnished for KDKA radio station and its various studios and pick-up points.

In the Plant Transportation Department are five branches of materials-handling activities, the work of each one being coordinated and fitted in with the others by centralized control from the general office. A brief description of each of these follows.

## The Standard-Gage Railroad

On account of the size and the layout of the plant, which places railroad tracks in each building where large apparatus is received or shipped, considerable use is made of these facilities and four 60-ton steam locomotives, with about 100 cars operating over 11 miles of track, are kept busy. This work is under the control of a yardmaster and an assistant.

Fig. 1 A Loaded Industrial Railway Train Showing the Miscellaneous Nature of the Work Handled in This Way

Recently trials have been made on this work with a Diesel oil-electric locomotive which proved the economy of this type over the steam locomotive; a saving of 35 per cent in operating and maintenance costs resulting. The tendency will be to replace steam power with the better fitted oil-electric haulage units.

## Automobiles and Trucks

To take care of material movement between plants in the Pittsburgh district, other than railroad movements, a fleet of eight trucks is maintained. Where needs are regular, scheduled service is maintained; where of an irregular nature, service is furnished on request. This same fleet takes care of local incoming and outgoing city movements. In this same department is operated a fleet of eight passenger cars which takes care of relief and medical-department work, as well as taxi service for officials, which is necessary on account of the scattered layout of the plant.

Maintenance of cars and trucks is taken care of within the department, the whole of which is in charge of a foreman.

## Industrial Railway

The industrial-railway department furnishes scheduled ser-

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vice to all parts of the plant, giving such frequency of service as to furnish about eight-hour delivery between any two points in the works. The railway service is mainly intended to take care of the movement of bulky or full-load material, such as castings from storage to manufacturing sections and scrap from these sections to the scrap house. Eleven storage-battery locomotives with six hundred $2^1/_2$- and 5-ton cars, running on $8^1/_2$ miles of 21-in. gage track, serve this department. Trains are made up to 25 tons of carrying load.

This work is in charge of a foreman, who has under him group leaders in charge of each route. Car movement is controlled by a movement tag which, when attached to a loaded car by a department, gives shipping directions and authority to move the car. A detachable stub on this tag is also used in billing the

Fig. 2 A Combination of Materials-Handling Units; Crane, Industrial Railway, and Elevator

department for railway service and as a basis of an incentive wage-payment plan which will be described under another heading.

### Cranes

Cranes form a vital link in the transportation system and are located throughout the works, in all buildings, storage yards, and transfer points. There are 172 electric traveling cranes in the works, with capacities up to 100 tons, located to serve the manufacturing sections, the storage yards, scrap-metal handling, and the transfer of material from one transportation unit to another. The operating control of these cranes rests mostly within the sections in which the units are located, but responsibility for maintenance and operator efficiency rests in a separate department under a foreman.

### Elevators

Efficiency of elevators has a considerable bearing on the operation of a transportation system, for nothing detracts from high running-time efficiency of trucks, etc., more than elevator waits. During the last two years the East Pittsburgh works has practically completed the revision of its elevator facilities, with the result that all multi-story buildings are served with standard 5-ton freight elevators equipped with direct-current motors and running at 100 ft. per min. with the necessary higher speed and smaller capacity, passenger elevators. A standard body, 11 ft. long by 8 ft. wide, is used, affording ample clearance for all loads handled on trucks. The elevators are built in fire-proof wells and fitted with all modern safety appliances. Operation and maintenance of elevators is under control of a foreman, the same foreman taking charge of this who has charge of cranes.

### Industrial Electric Trucks

For shipments of partial loads at intermittent intervals where the time element is more important, a fleet of 85 electric industrial trucks is used. Control is the most important feature in determining the efficiency and economy of this service. It must be readily available to be at all useful, and at the same time, trucks must be running at all times under as full a load as possible in order to secure efficiency. These two factors do not always work together, as time is an important production element, and the ordinary inclination is to disregard load efficiency in favor of the former.

To overcome this disadvantage, the shop was divided into districts and all trucking service for each district is handled by a dispatcher who has a sufficient number of trucks under his control to take care of all wants. From a reserve number of trucks made available by the increased efficiency afforded by this plan, trucks are added to the district if the production load increases, or if the load falls, trucks are added to the reserve. Close check is kept on the truck loading and only sufficient trucks to take care of the needs are kept in service. Requests for service are telephoned in to the dispatch station, in advance if possible, and are recorded and placed on a dispatch board. From this board the dispatcher makes up his loads, combining requests when possible, and assigning the work to the trucks as necessary. Work which must be handled regularly is scheduled and taken care of by the dispatcher without any special orders. The dispatchers in turn report by telephone at scheduled intervals to the works-transportation office, stating the number of loads and the time of the oldest load on their boards; as these fluctuate the trucks are shifted from one district to another so that daily peaks are taken care of and quick service is maintained. Provision is made for securing return loads by having the trucks stop at the other district dispatch stations on all return trips. However, most of this type of trucking is confined within the district since the industrial railway, as explained, takes care of bulk distant shipments.

Material from storerooms is delivered to the manufacturing sections through the dispatch stations. The section needing material telephones its requirements to the storeroom, the requisitions charging the material to the correct accounts are made out by the storeroom, the material ordered is removed from stock, placed in the proper containers, and loaded on truck skids which are picked up by lift trucks ordered from the dispatch station by the storeroom. The material, which in a greater number of occasions is in small lots, is then delivered by one truck, rather than by each section's sending its own truck or messenger. This eliminates a large number of partial-load hauls and also reduces expensive messenger service to a minimum.

Another odd job handled through the dispatch station is the delivery of the pay envelopes from the paymaster's office to the various pay stations located in the works. This is carried out on a schedule from which very little variation is allowed, but the trucks experience no trouble in meeting the close requirements.

In addition to this regular use of industrial electric trucks, there are special uses to which they are applied, resulting in lessened material-handling costs.

Three trucks are assigned as carrying units for a shop-express plan, corresponding to a parcel-post system, which handles packages of about the same sizes and weights. Four-hour

service is given to the entire East Pittsburgh works and other Westinghouse plants in the Pittsburgh district. About 900 packages are handled per day at a cost of three cents per package.

Tiering or high-lift trucks are used in the punch-press department for the handling of dies between machines and storage.

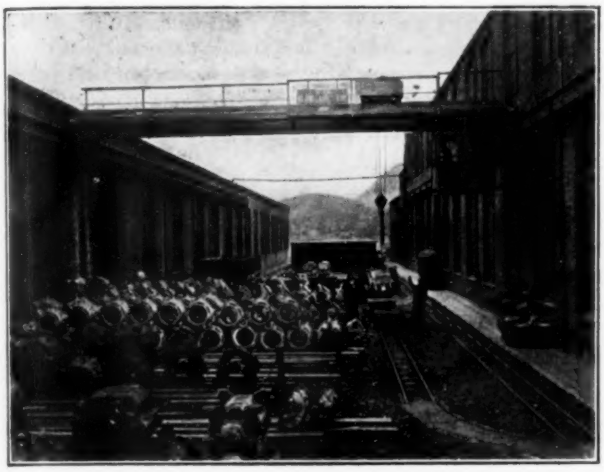

Fig. 3 Outdoor Casting Storage, Showing Materials-Handling Set-Up: Crane Which Can Serve the Standard-Gage Railroad, Industrial Railway, or Industrial Electric Trucks

In some departments it has been found economical to use trailers with trucks, thus doubling or bettering their capacity.

Another truck is fitted as an emergency wiring shop, enabling the wiring-gang quickly to reach and repair any break in the shop electric service.

Trucks collect all wood-scrap, garbage, etc. and take it to the refuse-burning boilers. This work is done at night, the trucks running on scheduled routes covering the whole plant. By doing the work at night, aisle congestion is avoided and better time is made.

Skids, or lifting platforms, are used extensively throughout the works. It was found that the standard skid, designed for the rather narrow platform of the standard electric lift truck, did not permit the handling of large enough loads where bulk rather than weight was the determining factor. So a skid 48 × 54 × $11^1/_2$ in. was adopted as standard, allowing more economical handling of such loads as boxed electrical goods, vacuum tubes, etc. To take care of this size skid, it was necessary to have the truck manufacturers furnish their lift trucks with a platform 40 × 50 in. instead of the 30-in. wide platform which is usually supplied. This size of platform allows the truck to be used as an ordinary platform truck, thereby adding flexibility to its application.

### Incentive Payment Plans

Coordination in itself makes for greater efficiency but at an early stage in the work it was seen that some method of increasing individual effort was necessary. The work was scattered over the whole plant, personal supervision of the foreman in charge was impossible except in a few cases, delays and waits on elevators and cranes were common, and investigation after the delay had occurred was of little use. It was felt that an incentive wage-payment plan placed on the various lines of work would help eliminate delays and stimulate personal effort on the part of transportation men; rather than sit down and wait for a crane lift the truck operator would hunt up a supervisor and insist that his work be taken care of in a reasonable length of time. To establish such a payment plan took considerable investigation and an attempt will now be made to show how a plan was worked for several of these activities.

### Industrial Railway

A survey of the plant was made and conditions affecting industrial-railway work were studied, such as routes to be followed, material handled, frequency of service necessary, and other factors. Routes were then established, taking these points into consideration.

Time studies were then taken over a period of several weeks, securing time values on the getting of loaded cars from the various sections and their disposition, the spotting of empty cars, the time in transit, and the time lost in transit due to various unavoidable delays.

An analysis of these studies showed the following detail operations:

1 Couple and uncouple car (performed twice per car)
2 Switch car (performed twice per car)
3 Deliver car (performed once per car)
4 Allowance for delays (allowed once per car).

The time for each of these detail operations was secured by taking the total detail time of each operation and dividing this by the total number of cars handled during the time of study.

This procedure is repeated for each manufacturing department served by the route.

From past records, the total number of cars handled per day for each section is secured, then by using these figures as a multiplying factor and dividing the sum by the total number of cars handled per day, an average time per car is secured, which is used as the base time for establishing a payment plan on the route studied.

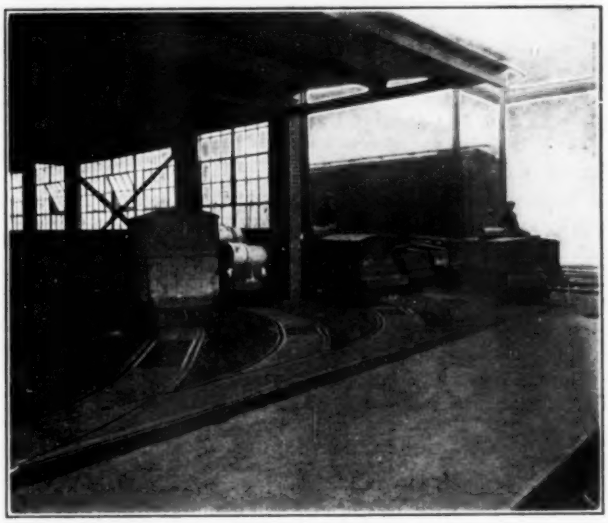

Fig. 4 The Classification Tracks Where Industrial Railway Trains Are Made Up by Yard Crews
(This corresponds to the classification track in any standard-gage railway yard.)

This figure is multiplied by the number of men in a crew (two) in order to secure the time in man-hours.

This is, of course, an average time and if applied to a single car movement would not check, but by using the group system of payment it proves accurate enough for all practical purposes.

In order to secure a check of the number of cars handled, a checker, stationed at the classification shed, keeps a list of the car numbers brought to the shed. This list, in conjunction

with the stubs of the regular car-movement tags which are pulled when the cars are delivered to their destination, gives a record of the number of cars handled and is forwarded to the payroll division as a basis of payment.

### The Group System

A brief explanation of the group system of payment is in order, since this is a part of all transportation payment plans.

A number of men, working on any certain operation or operations, are formed into a group under the leadership of one individual, called the group leader, who is responsible for the planning and direction of the work. The time made by the group is pooled for each pay period and distributed to each workman on the basis of the number of hours worked by each. Allowance for the time taken by the group leader in supervision is made on the basis of the number of workmen in the group.

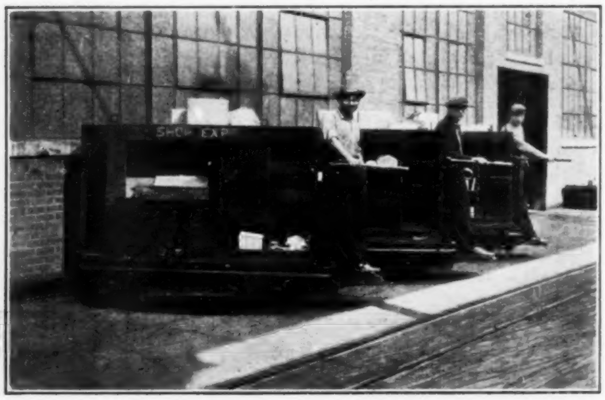

Fig. 5 Carrying Units for the Shop Express
The body design was adopted after considerable experimenting and combines carrying capacity with lightness and strength.)

Under the plan the time values, which are, as explained, necessarily average, can be applied and distributed over a pay period and the individual inequalities are smoothed out.

The group system is peculiarly fitted for transportation and materials-handling work as the members of the group, knowing that their pay depends upon the earnings of the group as a whole, do not hesitate to assist one another and thereby save many delays. If workers are paid on an individual basis, this is not always the case.

### Payment Plan on Industrial Trucking

Placing the industrial trucking on a dispatch system had greatly helped trucking efficiency but a limit seemed to have been reached where further gains to be secured by combining loads, routing of truck trips, use of trailers, and other factors could not be secured. The speed of the trucks was limited but it was felt that if the driver could be encouraged to use greater effort and exercise ingenuity to meet different situations, further economies could be made, so a wage-payment plan was established on this work. This was pioneer work, for although payment plans had been established on other truck work where the routes and work performed were standardized, here was an entirely different problem. Trips were on call, at one time the dispatcher might combine a number of calls into one load, at other times the same route would be covered to fill one call; sometimes trucks were loaded to capacity, at others only a small part of the capacity was used; lift-truck loads were different from platform loads since no loading and unloading time was involved.

The most practical way of basing payment was on the load or call as shown on the dispatcher's board ticket, so the problem was to secure a time value which could be applied to the average load.

Time studies were taken on the work from each manufacturing section served by the dispatch district, which showed the running time, loading time, unloading time, and delays of each type of truck used on the work. From these data, a time value for the average load from each section was secured. The next step was to secure a time value for the average load in the district.

From data secured on the time studies and from past records of the work performed in the district, the number of loads per day from each manufacturing section in the district was secured and this figure used as a multiplier of the time value for the average load. The total divided by the total number of loads gave a time value which could be used as a base time for each load or call on the dispatch board.

This was similar to the plan used on the industrial railway, but the studies disclosed one fact that had to be taken into consideration. That was the number of loads or calls per truck could be increased considerably without proportionate increase in effort on the part of the truck driver. As an example, if the shop was busy and the production load was large, there would be a large number of calls on the dispatch board at one time and the dispatcher would be able to group several loads in one truck trip. The loading and unloading would perhaps require more time and effort on the operator's part but the running time would show little variation, regardless of the load. From an analysis of these time studies and from studies taken over a larger period of time on similar work a multiplying factor was adopted, in this case 0.25, which then gave the true standard time on which payment was made.

As a check on the number of loads hauled, a small slip or "truck service" requisition was adopted. This slip is filled out and signed by the foreman of the section requesting the truck service, showing the section requesting material to be hauled, its destination, and the truck number answering the call. This slip is turned over to the trucker and at the end of his trip is turned in at the dispatch station. The slips are then checked against the call tickets taken from the dispatch board and furnish figures on which the payroll department makes up the pay.

This work is also under the group-system payment plan.

### Shop-Express Payment Plan

The three trucks operated as shop express carriers, as previously mentioned, are also paid on an incentive basis, studied in a similar manner and administered in almost the same way. There are a few additional points in this plan.

As the trucks must run on schedule, each trucker carries a card which is stamped by a time clock at several different points on the route; the payment plan provides a penalty for non-adherence to this schedule.

With such a large number of packages handled in such a short time, there is a possibility that goods will become damaged through hurried or careless handling. The payment plan provides a penalty for such cases.

Delivering to so many different points in the shop, there is a possibility that the driver will make a wrong delivery. The plan also penalizes for such mistakes.

Check on delivery and on quantity is provided for by the "shop express" shipping tag which must be attached to each article. This tag is serially numbered and has a detachable stub, both tag and stub show shipping section, destination, and identification number. Upon delivery of the material at the destination, the driver detaches the stub, stamps the delivery-station number on the back with a rubber stamp located at each station. At the end of the day the stubs are turned in to the works transportation office where they are counted and then filed numerically according to date. This file furnishes a ready reference for

information concerning delivery of any material shipped on the express trucks.

All transportation wage-payment plans involve the group system and the standard-time system of wage payment. These plans have been discussed fully in a paper[2] on "Coordinating Wage Incentives and Production Control" written by D. B. Charters of this Company.

Incentive payment plans are not as yet established on all materials-handling activities, in fact, not much more than a good start has been made, but with the successful installation on the part of the work where it is already used, there is reason to believe that such plans can be worked out for a greater part of the work, and under the direction of the time-study division, arrangements have been made to continue the work as rapidly as conditions permit.

## Economies

The economies resulting from this organization are not all measurable but nevertheless are of considerable benefit and their effect can be easily seen.

One of the gains in the organization as a whole is the fact that all transportation facilities are under one direction, which means that the production or planning department has to deal with but one department, leaving it to this department to move the material in the most efficient manner. If it is necessary to use more than the one transportation medium, transfer arrangements

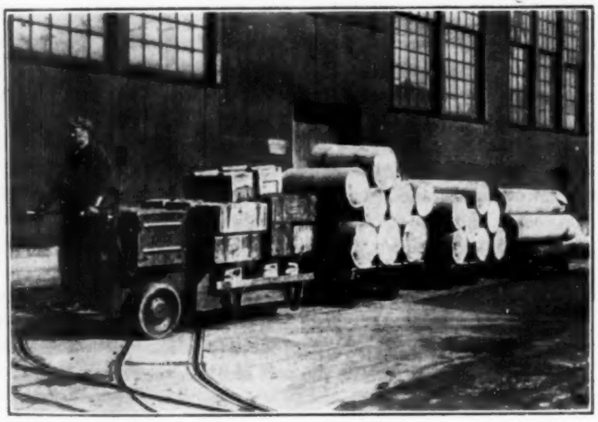

Fig. 6 An Economical Way of Handling Paper Stock (Showing the adaptability and capacity of the lift truck.)

can be made easily without referring to several department heads. As an example, a casting is to be brought from an outside source. This must first be loaded on an automobile truck and brought to the plant, then unloaded from the truck by crane to the industrial railway, and transferred to the section doing the first machining work. Without a central transportation department it would have been necessary for the production supervisor to get in touch with the truck department, the crane department, and finally the industrial-railway department.

In making layouts for new manufacturing sections the layout division needs only to consult with one department in order to arrange for transportation facilities. This also holds true of any other staff activity touching upon or desiring information covering transportation work.

Another economy, part of which can be measured, is that afforded by the installation of the truck-dispatch scheme. This supplanted a method of control in which trucks were assigned to departments under the direction of the individual foreman.

[2] See Trans. A.S.M.E., vol. 50, 1928, paper MAN-50-3.

Hand trucking between departments was practically eliminated because the industrial-truck service was made so readily available that the supervisor used it in preference to hand trucking. Any transportation scheme which does not take this fact into consideration and does not avoid all needless "red tape" can hardly hope to meet with success, for it is only with the full and un-

Fig. 7 An Industrial-Truck Dispatch Station Showing the Dispatch-Board Layout

forced cooperation of every line supervisor that efficiency can be secured. "Service" must be the slogan of a transportation department and this must be expressed in the working of the plan rather than by words.

Another saving is a decrease in accidents, both to workers and to material handled. This work by its very nature is peculiarly subject to such troubles but accidents were reduced and damage to goods in transit lessened mainly by the closer supervision afforded by the plan and the closer check on the work performed, with the opportunity of placing responsibility for accidents on the right party, not losing sight of the fact that with a central organization better opportunity is afforded for teaching safety-first methods and spreading safety-first propaganda.

Another gain was the better care given to equipment and a consequent lessening of maintenance costs as well as an improvement in appearance of the trucks, brought about by the fact that the dispatchers were close enough to the men to teach them pride in the appearance and operation of their trucks.

One way of computing saving caused by the installation of the dispatch plan and the incentive payment plan on the industrial truck work is to figure the number of trucks doing the work at present as compared to the number prior to the plan.

Formerly there were 88 trucks in service, some of these of course in stand-by service. At present there are 67 trucks in active service. Making allowance for six stand-bys in original

service, this shows a saving of 15 trucks. The operating cost of a truck is $130 per month. Subtracting from this saving of $1950 per month, the cost of running the dispatch stations per month, $950, we have a measurable saving of $1000 per month.

On industrial-railway work a similar calculation can be made. With the installation of an incentive payment plan, a reduction of three locomotives and crews was made. The monthly operating cost per locomotive and crew is $500. From the monthly saving of $1500 we subtract $550, the cost of administering and checking the plan, and a net saving of $950 results.

Close check is kept on the production load, and materials-handling facilities are kept in accord with this load. At the same time, check is kept on individual unit efficiencies and progress is being made on handling more material per unit, whether it be the railway or industrial truck. Under individual or sectional control it is hardly possible that materials-handling problems would receive the concentrated study given to it in the centralized department, for the attitude toward such problems would be influenced mostly by the effects on the section interested, while the effect on the plant as a whole would receive little consideration.

The organization as outlined is not a panacea for all materials-handling ills, nor is there any assurance that it is one which will take care of the problems of the future, but after trials of various methods of materials-handling control by the Westinghouse Electric & Manufacturing Company, it is believed that this more nearly meets their present-day requirements and shows better results than any other plan which has been offered.

## Discussion

G. H. Ashman.[3] Transportation at the General Electric plant follows rather different lines, although it is similar in some respects. All cranes and elevators, their maintenance, and their operators are under the control of one supervisor who has no connection with production work. Their movements, however, are entirely under the direction of the shop or section in which they are located. That applies also to yard cranes and all internal transportation. A separate transportation department has charge of the movement of all material outside of shop buildings, four distinct methods of transportation being in use: (1) standard-gage railroad, (2) narrow-gage railroad, (3) trucks, and (4) tractors and trailers.

Included in the equipment of the standard-gage railroad are two 75-ton and five 50-ton electric locomotives. The narrow-gage road employs ten locomotives, ranging from 30 tons down to 10 tons. There are 650 narrow-gage cars available.

The industrial trucks are 67 in number, ranging from $^1/_2$ ton to 5 tons. Of these 60 are electric and the rest are gas trucks.

A new system of tractor and trailer transportation has just been inaugurated, and while still in its infancy, the results indicate that it will be most economical. At the present it consists of 7 tractors and 250 trailers. In addition there are 46 passenger automobiles for official use, 7 of them with regular chauffeurs. Three electric buses operated on a regular schedule are run from one end of the plant to the other. The longest freight haul is about $1^1/_2$ miles, with the average around three-quarters of that. Approximately 6,500,000 sq. ft. of manufacturing and storage area must be collected from. This is a little more than the space noted by the author.

The standard-gage road handles the incoming and outgoing freight, also transporting the bulky material from one department to another. This operation is through a regular dispatching force of 11 men. There is a yard master, an assistant yard master, a night yard master, and a route manager. All have automobiles for keeping in touch with the crews in different parts of the yard.

All requests for transportation are forwarded by telephone to the dispatcher's office. A dispatch sheet is used rather than a dispatch board such as the author describes. The request is entered at the time of its receipt. Duplicate orders for the delivery of material are issued, on which are given the time the order is received, description of material, and destination. One copy is sent by mail to the man requesting the delivery, and the other is handed to the crew. Those two copies must check one against the other. This system applies to the standard-gage, narrow-gage, and to trucking, but not to the tractor-trailer system.

The tractor and trailer service is a new and interesting development, flexible and instantly adaptable to sudden changes in routing. This plant is divided into five zones, each zone being tended with a separate shuttle service. Every department in each of these shuttle-service zones has its own platform to which material, either in package or carload lots, is delivered and from which collections are made by the shuttle tractor. Located in the middle of the plant is a classification yard, and shuttle tractors deliver to and receive their trailers from this central point.

Both gas and electric tractors are being used, and also a gas-electric type in which the power plant, consisting of a gas-electric generator, has been adapted to fit in the battery compartment of a standard battery truck. With this latter, maximum power is at all times available, with no loss of tractor effort due to partly discharged batteries.

The group or premium plan of wage payment is not used, operators at present being paid straight day work. The cost of deliveries is computed from the completed trip, a completed trip being delivery of the empty car or the empty trailer for loading and its delivery to destination when loaded.

The cost of a complete trip on the standard-gage averages $3.50 and for the narrow-gage about $1.15, these figures of course including all overhead expenses. For the tractor-trailer system the cost is only about 36 cents. The cost of operating the truck as given by the author, seems exceptionally low. From records of operation with which the writer is familiar, with two men to a crew, labor alone would amount to about $220. The gas consumption of a truck averaging 775 miles per month costs around $22, and the average repairs, including tires, amount to about $35. The writer cannot see how the cost of $130, as given in the paper, was attained.

William Elmer.[4] The writer was recently astonished to learn in a conversation with a representative of the Department of Commerce that the total bill for materials handling in this country for 1926 amounted to four billion dollars. That includes the large unit carloads of coal, ore, etc. which are handled over dumping machines, but when we segregate the cost of handling materials carried in small lots, there are various estimates, but the figures approximate a billion dollars a year. This is subject to a considerable reduction by the use of such methods of transportation as have been developed by the author of this paper.

The individual studies in certain plants have shown savings of as high as 90 per cent in the cost of handling materials. Those figures seem almost impossible, yet when the details have been studied both before and after the introduction of improved methods they check. Assuming that such a figure as 50 per cent is realizable, one can see that there is a mark worth shooting at—a saving of half a billion dollars a year in the materials handling of this country. Suppose that 50 per cent is too great; halve it, and there is still a quarter of a billion dollar saving.

The individual skid mentioned in the paper was selected on the

[3] General Electric Company, Schenectady, N. Y.

[4] Special Engineer, Pennsylvania Railroad Co., Philadelphia, Pa. Mem. A.S.M.E.

basis of experience. There are various types of manufactured skids as well as the home-made variety which are in use to the extent of hundreds of thousands.

One of the largest manufacturers of trucks has said that he would willingly scrap all their dies, patterns, and materials if a standard skid or a few standard sizes could be agreed upon. Since a great deal of future freight movement will be made by standard-gage railway cars, it is evidently quite desirable to select a type of skid which can be used satisfactorily in box-car shipments, the idea being that when the material is shipped it can be loaded on skids.

On reaching its destination it would be handled by the receiver's skid trucks. If a skid can be chosen which will pack into freight cars and allow the loads to be properly wedged and set for transportation so that the shocks of handling cars and railroad service will not damage the goods, undoubtedly large sums of money can be saved.

H. P. Reid.[5] One of the greatest problems of a standardization program lies in the great difficulty in meeting the different floor levels, the car-door size, the car size, and the eaves height. The floor levels constitute a great difficulty in the perfection of any kind of a standard box-car loader.

The product of the writer's company goes out entirely weighing 95 lb. These sacks are loaded from 500 to 1200 or 1300 sacks per carload, which means stacking from four high in the larger loads. Many attempts have been made to develop a car loader for such packages, but thus far none has proved satisfactory, so far as the writer has been able to determine.

Up until a year or two ago a standard box car was used by the writer's company for the transportation of empties from the recovery and reclamation departments back to the packing department. It was found after a careful study that the time cost could be greatly reduced and the different stations supplied much more satisfactorily with empties by the use of an auto truck of special design. The loading stations for these empties are such that three different auto-loading platforms must be used. The distribution stations for this auto truck are 11 in one plant and are so scattered as to require trips for the auto truck of from a few hundred feet to half a mile. To cover this area with a sort of transportation system, from four to eight railroad switching tracks must be crossed.

An automobile truck with a lifting body to take care of the deflection of the springs as the load is applied was developed. This special-bodied truck with the use of platform trucks on caster wheels has reduced the costs of handling of empties about 50 per cent. The system paid for itself within twelve months.

This company uses special-size platform trucks employing two rigid and two castering wheels. For this service the wheel-mounted platforms have been found far superior to the skids and lift truck. The returned empties are kept on wheels from the time they are received and unloaded from the railroad cars or from automobile trucks until they go into storage, and as they are taken out again, they are again kept on wheels until they have been filled at the packing plant.

It has also been necessary to develop a special-width platform truck for unloading cars. It was found possible to build a truck which would handle roughly 2 tons on four wheels, using aluminum instead of rubber tires, and one handled by two men which could be run into the box car, so that receipts from different shippers when mixed in the railroad car could be sorted, and the movement of these sorted shipments was much easier and speedier than could be accomplished with skids.

The experience of the writer's company with lift trucks has been that the floors and runways have to be comparatively level to permit their operation. They cannot take care of heavy deflections in the floor nor turn corners readily on inclines, as for instance from the unloading platform to car-floor levels.

G. F. Tegan.[6] At the Swissvale plant of the Union Switch and Signal Company the coke formerly was brought in box cars and unloaded in the orthodox fashion, that is, by wheelbarrows, shovels, etc. The limestone was handled in much the same way, and the pig iron and scrap were handled in open-top cars with a magnetic crane.

Lately there have been certain changes in handling methods. Bins were built in the ground, and a trestle was erected for handling the coke and limestone. The old track was used for unloading the pig iron and scrap, which is dropped. As a result of those improvements, the superintendent of that plant said that they had reduced their man-hours from 49 to 22 and had cut the total cost of handling materials in their foundry practically two-thirds.

P. W. Power.[7] Owing to the writer's work at the Pittsfield plant of the General Electric Company in connection with the provision and use of equipment, there are points in this paper that are of special interest in connection with that work.

Owing to the location, the long winters with accompanying snow and ice made the elimination of the narrow-gage track desirable. The substitution of tractors and trailers has proved to be of great advantage, since the cost of clearing snow and ice out of the grooves of the rails sometimes amounted to more than the trucking costs.

Another point worthy of mention in connection with transportation by means of tractors and trailers is that a good runway or roadway is quite necessary to complete success. In the case of the Pittsfield plant, paving extensions of either concrete or brick, both outside and in the shops, made corresponding reductions in costs of maintenance of floors and roadways and the ability to carry heavier loads and carry as high as 8 tons. The problem in this case is to get good wheels. Iron- and steel-tired wheels were used in the beginning, but it was found that wheels would occasionally break, and also they would damage the floors.

Metal tires have been abandoned in favor of rubber tires, and little by little the quality of these has improved until now experiments with a recent type indicate that soon we shall have rubber tires that will withstand greater traffic over greasy and oily floors.

When the more extensive use of tractors, trailers, and trucks was inaugurated at the Pittsfield plant seven or eight years ago, it was not so easy as it now is to purchase satisfactory trailers. Some were made at the plant and others were purchased. A good deal of expense was required for maintenance, for the bearings particularly.

The millwright department always had two or three trailers under repair. Roller bearings of the spiral-wound type were tried. Their use has been extended until for the past three and one-half years no other type of bearing has been employed. A recent check-up of these bearings on 600 trailers in use disclosed the fact that to date no money has been spent on maintenance, repairs, or renewals.

The matter of skids has been referred to. The writer would be very glad indeed to find and use the standard skid that may be adopted. A large sum has been spent in making skids, both platform and box types. They are expensive to use and maintain, and it seems that if a standard size was produced it would be of very great value and very good for interchangeable service.

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[5] Universal Portland Cement Co., 210 South La Salle Street, Chicago, Ill.

[6] Editorial Representative, *Iron Age*, in Pittsburgh, Pa.

[7] Mechanical Engineer, General Electric Co., Pittsfield, Mass. Mem. A.S.M.E.

The writer would like to obtain information on a good method of handling copper wire on reels weighing 250 lb. each. The damage and the wear and tear to reels are very high, and a really good method of handling does not seem to be available. Perhaps the author can enlighten us.

Charles C. Leeds.[8] It would be interesting to know if a study has been made as to the relative cost of electric versus gasoline trucks, and if so, what results were obtained. The speaker would also be interested to know if the system worked out by the Westinghouse Company does not require a rather elaborate clerical force to handle the system, forms and checking, etc.

Charles B. Patt.[9] It would be helpful if the author in his closure would explain whether the transportation department has charge of the upkeep of all the transportation facilities including the elevators and cranes, trucks, tractors, and so forth, or whether it comes under the head of the mechanical division and they simply look after the operation.

### Author's Closure

The author's paper handled the problem from the standpoint of management; that is, organization and control. The discussion brought out by the several people is not from exactly the same angle. However, various points are brought out that perhaps can be answered.

Mr. Reid's experience with lift trucks and skids closely coincides with our own, and our conclusions are the same.

We can understand Mr. Power's difficulty with industrial railway installation. In our East Pittsburgh plant we do not have so much difficulty with snow removal as the tracks are laid on ties in line with standard-gage railroad practice in nearly every case where the installation is outside of the buildings. For this reason we have not seen fit to supplant the industrial railway with tractor and trailer, although there are some places where trailers are used to a considerable extent in conjunction with the electric industrial trucks.

Our experience with wheels and bearings is the same as that given by Mr. Power; that is, we found that the rubber tires are the best and the use of the roller bearings has eliminated our trouble in that respect.

We are unable to furnish much help in Mr. Power's inquiry concerning the proper method of handling copper wire on reels. We use a sling for handling by crane to the trucks or cars and unload by hand, using a "beer mat" to break the force of the contact and eliminate reel breakage. We know this is not a very good plan, but it is the best of which we have been able to secure any knowledge.

[8] Carnegie Institute of Technology, Pittsburgh, Pa.

[9] American Steel & Wire Co., Pittsburgh, Pa.

Mr. Elmer brings out some very interesting points concerning skids, and we agree that it would be of greater advantage to have standard skids and make shipment of material between supplier and consumer by means of skids which would fit on standard-gage railroad cars. I believe there has been some progress made in this respect with sheet steel in some of the automobile plants, and recently we have been spending some time in research on this same question.

Mr. Leeds makes an inquiry concerning electric versus gasoline trucks. We presume that he means trucks built for outside road service. We have made some studies and accumulated some data on this, and we find that if conditions are suitable for the use of an electric truck—that is, short hauling with fairly level roads—comparison is in favor of the electric truck. Under other conditions—that is, long hauling, infrequent stops, and hilly roads—the gasoline truck is the more economical. It may be that Mr. Leeds refers to the gas-electric industrial truck which has been mentioned by Mr. Ashman. In this case we have not accumulated any data, but our studies again show in favor of the electric truck, basing our conclusions on the cost of operation of a gasoline truck compared to that of an electric truck. No doubt there are exceptions to this conclusion, one of which would be if charging power was not readily available.

Regarding the clerical force which is needed to handle the organization and about which inquiry is made by Mr. Leeds, I would say that the clerical force is smaller than under any former organization. One clerk takes care of the forms and checking, with the part time of two other clerks who assist in taking care of the wage-payment plans. This of course is in addition to the regular supervisory force of the organization.

Mr. Patt inquires concerning the upkeep of the transportation facilities. Within the plant transportation organization we have one department designated as the transportation maintenance department which takes care of the maintenance and upkeep of all transportation equipment with the exception of cranes and elevators, which owing to their complicated nature, involving both mechanical and electrical repair work, are taken care of by a separate department. The operation of cranes and elevators is directly controlled by the manufacturing departments in which they are located, and responsibility for their proper operation and maintenance is located in this other department. This will also answer the question brought out by Mr. Ashman. The cost figure which Mr. Ashman brings out and which he questions in our case is the figure for an electric industrial truck. The figure which he uses as a comparison is, I believe, a gasoline road truck, which of course would not check with ours. Our gasoline road truck costs are based on the cost per mile, which varies according to the capacity of the truck. A $3^1/_2$-ton truck costs about 50 cents per mile, including overhead, depreciation, and all other factors.

MH-50-9

# Handling Methods and Equipment in a Large Mail-Order House

By H. E. ODENATH,[1] PHILADELPHIA, PA.

In production by modern handling methods each type or kind of industry has a specific object it desires to attain by installing such methods. In many industries the main object is reduction of cost by eliminating waste motion or hand labor. With a large mail-order house, more than in any other industry, the chief object is time. Speed is an essential in handling the orders, as it helps to make and to keep the good will of customers.

Next to the time element must be reliability of equipment. Supervision and inspection enter prominently into this, for breakdowns are always disastrous.

As with all continuous-flow materials-handling systems once it is in satisfactory operation it becomes a medium for excellent production control and timing of production; so that with our present system of handling orders, which is a development of many years, we need only to put a satisfactory timing on each operation of each order to secure a successful continuous flow of filled orders.

Before going through the layout of production, it might be helpful to outline our problems. In developing this system we are faced with the necessity of handling as high as 50,000 individual orders a day. These vary from trifles such as toothpicks and handkerchiefs to stoves, rugs, and farming implements. Some orders are filled in one merchandise department, while others must be filled by contributions from many widely separated departments.

This makes it necessary to have not only a system of handling the merchandise but to have a reliable system of handling the invoices to different departments, with rapid methods of indexing, filing, recording cash, separating orders for the departments, and timing completion of orders.

The first part of our systems may be described as mass production of bookkeeping, indexing, filing, cashiering, and scheduling, and the second part as mass production of picking goods, assembling, wrapping, weighing, and stamping of merchandise to thousands of customers.

From the layout of our plant (Fig. 1) the flow of orders can be followed. Our mail truck picks up at the North Philadelphia post office the first morning mail and delivers it to the sixth floor of the office building, where the pouches before being opened are thrown on the scale and the net weight of all mail determined for this trip. From this weight our managers are able to approximate the volume of business for the day, and the pressure of the work schedule is arranged accordingly.

The operators open this mail at the rate of 400 to 500 pieces a minute with an electric slicing machine that cuts the envelopes without mutilating the contents. The orders are pinned to a temporary file back, and the amount of the cash or check enclosed is entered in pencil on the face of the order. The cash is counted in a division of the cashier's office on the left, and the orders after being balanced with the cash are placed on a belt. From this point the orders are delivered through a gravity chute to the entry department on the floor below.

When a customer's orders must be filled from two or more departments, the items must be separated, and that is done in the entry department. An invoice is made for each department represented on the order, and the completed invoices and the original order are pinned and placed on the moving belt. There are four such belts in this room for conveying the mail to the rear of the room.

As was done on the sixth floor, this department also dispatches its finished work through the chute to the floor below, which is the general index department, with a capacity for holding and recording the accounts of 3,000,000 customers. As the orders arrive from the fifth floor they are handed to the operators who sit at the beginning of these belt conveyors. These look like long channels, as there are partitions between the six 2-in. leather belts (Fig. 2), the longest of these runs to the end of the room and the shortest to the first aisle. The orders are sorted alphabetically, and they are then routed by the belts to the proper sections of the department. Those beginning with A, B, and C

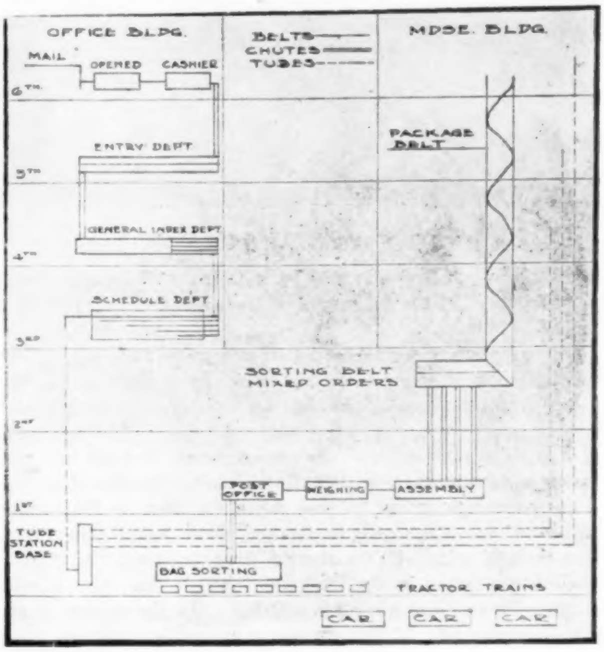



Fig. 1 Routing of Orders

go to one station, D and E to another, and so on. The index is arranged by towns in alphabetic order. This is done to avoid the congestion that would result if a geographic division by states and counties and towns was used, as business from one section of our territory is sometimes heavier than from others.

At every row of file cabinets is a station for further sorting the orders. There are six or seven of these stations. From here the orders are delivered by messenger to the operators in that row. The belts merely deliver the orders to the different stations. The file cabinets are placed back to back against the belts which carry the completed work to the rear of this room. These belts discharge on one high-speed belt underneath the platform.

The completed work leaves the department through a chute that discharges on the floor below in the scheduling department. In this room are addressograph machines, the address plates of

[1] Chief Engineer, Sears, Roebuck & Co. Mem. A.S.M.E.

Presented at the First National Meeting of the A.S.M.E. Materials Handling Division, Philadelphia, Pa., April 23 and 24, 1928.

each corresponding with one section of the shipping room. There the several invoices for each order are stamped with the same schedule. This consists of the shipping-room division, section, and basket numbers and the time due. The time for each shipping-room section is changed every ten minutes. This avoids

FIG. 2 DISTRIBUTING ORDERS BY BELTS

duplication and provides for an automatic distribution and control of work. In the technique of the store this referred to as "schedule."

The invoices are sorted by departments and time into a long row of bins which form a sorting rack. From here on they are called tickets and are dispatched to the different merchandise departments by a system of pneumatic tubes. The bins hold tube carriers stenciled for the departments, and on the rails above the bins are narrow belts which convey the closed carriers to the pneumatic tubes. These tubes are used in dispatching mail from one department to another, there being three trunk lines each of which serves several departments. The regular schedule on orders is also handled through this tube system, making it possible to work our schedule. In the course of one day approximately 25,500 carriers are handled through these stations.

In the pneumatic tube relay, station boys transfer the carriers from one line to another for delivery to the merchandise departments, where the orders are priced and the sales are listed. After the orders clear the ticket office the merchandise is picked up and carried to the rechecking and wrapping table (Fig. 3) and given a protective wrapping, and then is placed on a conveyor which discharges to a spiral chute which delivers on belts in the sorting department (Fig. 4) on the second floor of the merchandise building. This department receives, sorts, and distributes the mixed merchandise to the assembly room below. "Mixed merchandise" is an order that must be filled from more than one department. This merchandise is received in the sorting department from the merchandise departments on a 10-min. schedule. It is permissible for departments to send their merchandise 25 min. before schedule, but not a minute later, under the penalty of being charged 50 cents for each piece received late. This charge is credited to the shipping room and is deducted from the department charged. In sending merchandise 25 min. ahead of schedule the sorting department is enabled to sort three schedules at one time from the primary or sorting belt. In the secondary sorting two schedules are sorted at one time according to sections and distributed over conveyors to those sections, the last order being released to the assembly room of sections 15 min. after the schedule is sorted.

In the assembling room the orders are checked in canvas baskets according to schedule on order. When complete, the orders are packed and sent over conveying belts to the weighing division. Orders that are not completed on time because the merchandise was received too late or for some other irregularity are held for one hour, and then if not completed, they are sent as they are, and a second shipment is made later and the charges prorated.

In the weighing division (Fig. 5) all parcel-post shipments are received over a conveying belt and are cleared from the tables on either side once every hour to the post office on the same floor. The mode of distribution to the post office is also by conveyors.

Here the postage is affixed by weighers who use computing scales. The packages are received on the 48-in. belt conveyor, which passes through a movable distributing carriage. The belt as it reaches the carriage turns back over a roller, and then passing around a second roller goes underneath the carriage. This distributing carriage (shown in Fig. 5, upper center) travels back and forth the length of the scale tables, while the belt moves forward and drops the packages to a short transverse belt mounted on the traveling carriage and moving up and down the aisle with it. This transverse belt is reversible so as to discharge to the scale tables on either side.

Single orders, or orders filled in one department, are picked, checked, and packed by the department receiving them and sent

FIG. 3 TYPICAL WRAPPING DEPARTMENT WITH CONVEYOR

to the weighing division over conveyors without going through the sorting and assembling processes of the mixed orders.

Freight and express orders average only 5 per cent of all orders received, and are therefore handled on a smaller and different scale.

The operatives in the post-office division are employees of the Government. The outgoing mail is sorted into pouches ac-

cording to towns and states. There are five conveyors between the floor and ceiling directly over each other. Adjacent to these belts are the operating galleries where the mail is sorted.

The post office uses 3110 sacks to make this separation. The mail sacks are lettered, and when full they are tied and locked and then placed on conveyors for the sorting platforms in the basement, where they are sorted for the railway mail cars, which also are designated by letters. The men in the basement place these sacks in trucks destined for the platform of the individual cars. These trucks are made up into trains so that they may be tractored out in the order in which the cars are spotted on the tracks and are then unloaded into the cars. This separation by number and position, as laid out by the post office, enables the clerk who works in a particular car to dispatch all mail as it reaches its destination. In this mail handling we average about 9000 sacks daily, and during the holiday season we have reached a peak of 25,703 sacks. Our average number of mail cars is 23, and for a peak day, 35 cars. At such a time we are required to make two shifts in the switching of our mail cars. Our platform space enables us to spot 45 regular box cars. We unload about 35 cars per day of incoming merchandise. We load 15 to 17 cars of outbound freight, using the box cars unloaded.

In the unloading of inbound merchandise on straight carloads it is placed on departmental trucks set on the platform with one end against the side of the car. The car checker attaches tags to these trucks showing the quantity and catalog number, truck number, and the car from which this merchandise is unloaded. This tag is taken from the truck by the man receiving and piling this merchandise in a department, who verifies the quantity as he puts it in stock. This is used for our check, and the quantities taken from these tags are entered on tally sheet.

The forwarding of the merchandise from the cars to the different departments is done by truckers who make up train loads from the cars to the various elevators.

Fig. 4 Merchandise Separation in Sorting Division

Fig. 5 Weighing Department Where Postage Is Affixed

Fig. 6 Package-Mailing Department

## Discussion

### Author's Closure

S. D. Graff[2] asks what percentage of time is required for handling the order.

B. A. Hildebrant[3] asks about the time. The merchandise departments are allowed 2 hours and 10 minutes before the schedule is due. The shipping rooms are allowed 1 hour and 15 minutes. As to the red and blue colors, the red label is used for parcel post and the blue for first-class mail; a stamping machine is used, but for parcel-post work precanceled stamps are dampened on a sponge and stuck on the package.

A. F. Mojesctic[4] asks about the penalties. The departments may send packages to the sorting department 25 min. ahead of schedule but no sooner, because the sorters have time only for three 10-minute sortings. A penalty for a "late" is charged to the department making the error, and the shipping department gets the 50 cents credit because of the separate handling and ticket.

[2] Dennison Mfg. Co., Boston, Mass.

[3] Industrial Engineer, Head Methods Dept., Norton Co., Worcester, Mass. Mem. A.S.M.E.

[4] Cleveland Tram Rail Co., Cleveland, Ohio.

As to M. Lee's[5] question on the maintenance of equipment, when we started in Philadelphia eight years ago we had 46 conveyors and now we have 110. When we first started we had four men oiling and on general maintenance work and cleaning the motors, and we now have only two men to look after them. I give the credit mostly to the fact that we have almost entirely equipped the main bearings with ball bearings. We have had savings as high as 57 per cent in the power consumption. The maintenance cost for the system of belt conveyors is $300 to $350 a month. The capital investment is $1000 to $1200 each.

Prof. George W. Kelsey[6] asks as to the weighing of mail in the morning as a guide for laying out the day's work schedules. None of the mail is opened to see if it is an order or a complaint or is general correspondence.

The plan has been worked out over a period of years on the law of averages, and it holds good to very close accuracy. They simply weigh a sack full of mail, and from that they can judge within a very few dollars the amount of money and very close to the number of orders.

[5] Eastman Kodak Co., Rochester, N. Y.

[6] Assistant Professor, Industrial Extension Division, Rutgers University, New Brunswick, N. J. Jun. A.S.M.E.

After the mail is opened the longhand letters are typewritten.

As to whether stock is carried in a filling or retail department, in some sections there are storage stocks and in others the stock is carried on the same floor so that moving it into the open stock requires a travel of only 50 to 100 ft. Where a very large stock is needed it will be stored in the nearest space to the department using that merchandise.

Such a thing as "hand handling" could not be done on the scale we do things. From the start the handling by machinery was one of the first things arranged.

Materials coming in from a car are loaded on trucks, run on the elevators, delivered to the merchandise departments, and stored by lifting machines.

Wooden shelving is used in the storerooms because departments are moved quite frequently, sometimes over a week end. Wood is more adaptable, and these quick changes could not be made with steel. The time in cutting down and reassembling would be too much. The wooden shelf units are of the same size, width, and depth, consequently they are adaptable to any department.

The handling of 25,000 orders a day requires an accurate shipping schedule.

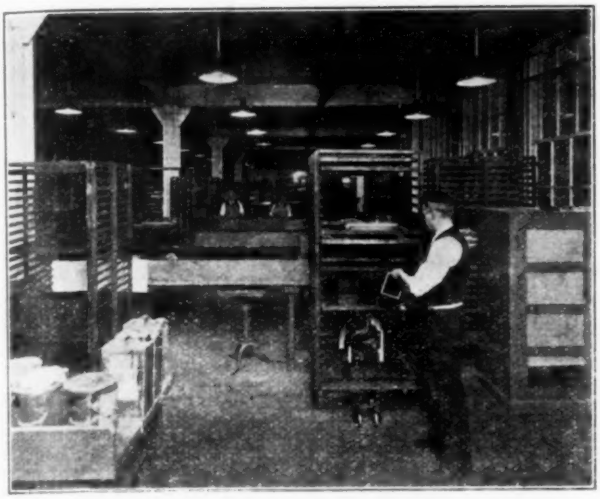


FIG. 1 SHOWING TYPE OF TRUCK FORMERLY USED

FIG. 2 SHOWING SPRAY BOOTH PREVIOUSLY USED
(Note handlings necessary from truck to spray booth and return.)

# Modern Handling in Enameling Work

BY E. D. SMITH,[1] DAYTON, OHIO

STUDIES of rearrangement plans of the enameling or finishing department of The National Cash Register Co., Dayton, Ohio, were made having in mind the following reasons for such rearrangement:

1 Increased capacity was needed
2 To provide this capacity with existing methods demanded additional floor space which was not available
3 Lower departmental cost, as always, was desirable.

### GENERAL

In an effort to meet the demands as above indicated a careful study of the department was made to see whether it could be changed over from the hand- or push-truck method of handling to perhaps a somewhat modified system of continuous-flow manufacture. The study very early indicated that a large portion of the labor expense was occasioned by numerous handlings. (Figs. 1 and 2.) The nature of the product to be handled was such that handlings must be carefully, even if expensively, made. It was therefore quite obvious that a reduction in the number of handlings was not only desirable from a quality standpoint but should offer substantial savings. After completion of rather extensive time studies an experimental installation was made in order to answer, at least in part, the following questions:

(1) Could the cabinet parts be successfully sprayed with both ground coat and lacquer while in motion?
(2) Could parts be suspended from chains in sufficient number to secure desired output?
(3) Could the vapor and fumes from spray guns be removed in such a manner as to not interfere with the operators' efficiency or health?

### EXPERIMENTAL INSTALLATION

Very few demonstrations were necessary to prove that the spraying could be done while material was in motion. The question of securing sufficient capacity on a chain moving past the operator at a satisfactory rate presented a very considerable problem. There were hundreds of different kinds of pieces varying in size and shape from a half-dollar to complete cabinets not unlike a small trunk. (See Fig. 3.) This was a problem that could only be solved by actual experiment, and a great many different kinds of hangers or trees were tried out. By the process of elimination and change the number of hangers required was finally reduced to nine. These were very simple and inexpensive to make. (See Fig. 4.)

### SPRAY BOOTHS

The removal of vapor and fumes was purely a question of moving the air past the part being sprayed with sufficient rapidity to prevent fumes or vapor from flying back into the operator's face. Spray booths were installed in separate rooms. A slight static pressure is maintained in these rooms by delivery of filtered and tempered air from a fan system. The delivery of air to the room is about 25 per cent in excess of that removed by the suction system. This produces very satisfactory conditions, and there are no complaints from the operators because of air conditions.

In order to prevent drafts or air blasts, the discharge ends of air supply ducts in spray rooms were covered with a very large area of fine-mesh bag similar to those on a standard vacuum cleaner. These are to be seen in Fig. 5.

### BURN-OFF OVEN

In lieu of the washing system formerly used, a burn-off oven was provided. (See Fig. 6.) Parts pass through this oven on a wire belt and are subjected to a temperature of 1000 deg. fahr. for about four minutes. This removes in a very satisfactory manner all the oil, grease, dust, etc. which naturally accumulates during shop handling and fabrication.

The present operations or processes in enameling are as follows:

(a) Clean in burn-off oven
(b) Spray with first ground-coat color
(c) Bake ninety minutes at 230 deg. fahr.

[1] Maintenance Engineer, The National Cash Register Co. Mem. A.S.M.E.

Presented at the First National Meeting of the A.S.M.E. Materials Handling Division, Philadelphia, Pa., April 23 to 24, 1928.

(*d*) Putty where necessary to get perfectly smooth surface
(*e*) Spray with second ground-coat color
(*f*) Bake ninety minutes at 230 deg. fahr.
(*g*) Sand for smoothness
(*h*) Grain to produce natural-wood appearance
(*i*) Bake ninety minutes at 230 deg. fahr.
(*j*) Spray with first coat of lacquer
(*k*) Bake forty-five minutes at 110 deg. fahr.

Fig. 3 Showing Parts Making Up a Complete Cabinet
(Note variation in size and shape.)

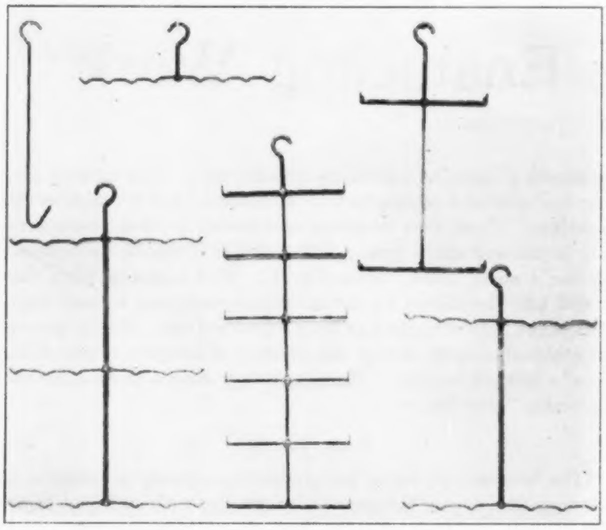


Fig. 4 Showing Six of Nine Standard Hangers in Use

(*l*) Spray with second coat of lacquer
(*m*) Bake forty-five minutes at 110 deg. fahr.
(*n*) Rub.

In passing through these fourteen operations or processes the work is removed from the chain but four times.

### Vertical Movement—Basement to Fourth Floor

The raw-stock storeroom is in the basement and the enameling department is on the fourth floor, therefore economical and continuous movement of stock between these floors was an important part of the scheme. This was very satisfactorily worked out by installing a series or ramps or risers in chains. (See Fig. 7.) The maximum obtainable angle of rise was 20 deg. so that to travel the necessary vertical distance of 51 ft. it was necessary to use 14 risers. As the finished-stock room was also in the basement, the same scheme of delivery from fourth floor to basement was used.

### Ovens

All ovens except those at high temperature for special finish are heated by air passed over steam coils. With the continuous type of oven, such as used, the cubic content was necessarily large and in order to make up for losses and to bring incoming material up to temperature promptly a large number of air changes were required. In the case of ground-coat oven this amounts to 31 per hour.

### Results

The whole installation has worked out very satisfactorily, resulting in savings as listed below:

(1) Annual payroll reduced $59,000
(2) Maximum daily output increased from 600 to 800 units
(3) Floor space reduced 10,000 sq. ft.
(4) Number of handlings reduced from 58 to 20
(5) Improved quality of production due to decreased handling and improved banking conditions
(6) Departmental turn over time reduced from $7^1/_2$ to $1^1/_2$ days.
(7) Reduction of inventory of cabinets and parts 80 per cent.

## Discussion

J. B. Webb.[2] The type of conveyor described is a good illustration of the flow idea in manufacturing: that is, to keep the product

[2] President, J. B. Webb Co., Detroit, Mich. Mem A.S.M.E.

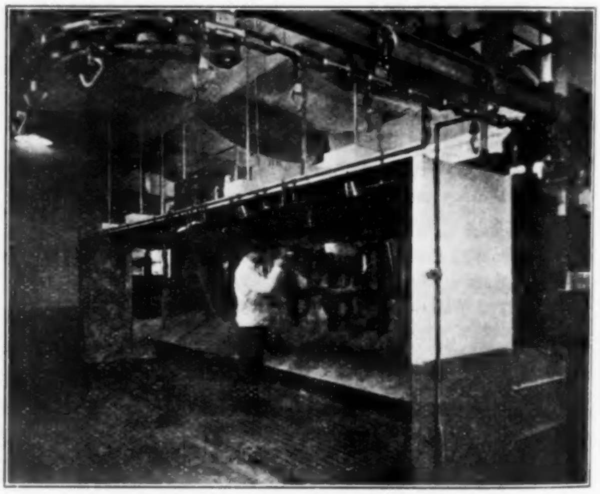


Fig. 5 View Showing Operator at Work in Spray Booth and Air-Diffusing Bags

Fig. 6 Discharge End of Burn-Off Oven

moving. A great many industries are beginning to think about this now more than ever. Credit can be given to the automotive industries for realizing its value to the fullest extent. The minute any labor is performed on a piece of goods, it must be put on the move and sent on to the consumer so that the money for it can be returned as soon as possible and that inventories can be reduced.

There is another factor of primary importance, in fact, of greatest importance, and that is that the flow idea in conveyors means pace making. The work is brought to a man at a definite rate of speed, and is taken away from him at a definite time; he has just so much time to perform his work, and he will do it and consistently keep doing it, while if the time is optional with him he always takes more time than is necessary.

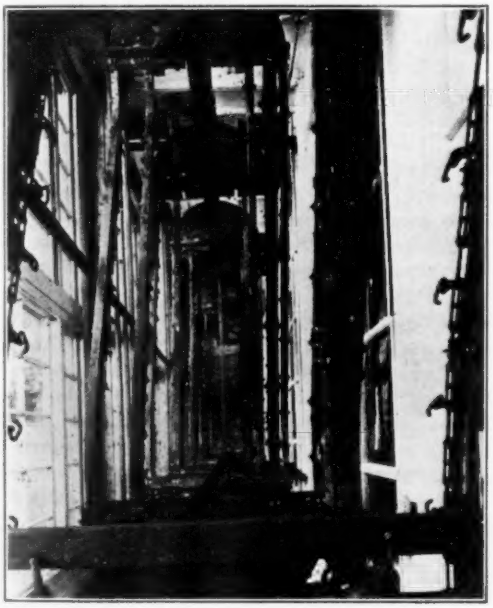


Fig. 7 Looking Down From Fifth Floor Showing Series of Ramps or Risers in Conveyor

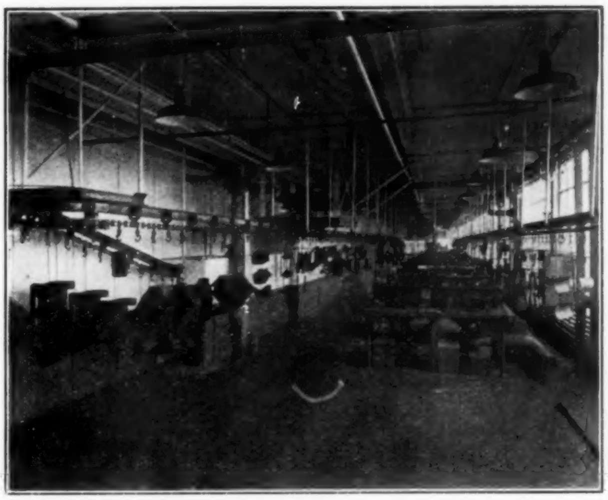


Fig. 8 General View Showing Cabinets Leaving Oven and Sanding Section

I know from practical experience that where work of an assembling nature has been done so that one man performing an operation passes the piece on to the next one, astonishing increases in production have been effected by placing that work on a moving system so the man's time for doing the operation is in the hands of the management and not in the hands of the man himself.

## Author's Closure

In answer to several questions, I would say that the drives of the conveyors are all variable in speed. The predetermined speed by calculation was $7^1/_2$ ft. per min. and we have adhered very closely to that.

As to the relief of operators, we use a handy man who keeps the operators supplied with material and gives them relief when necessary, helps to clean up booths, and so on. We do not have extra operators. We have to have this man anyhow.

We have very few rejections with this scheme now. Rejected pieces are usually laid aside and orders are telephoned to finish another similar piece and send it through.

# Marine Terminal Operation

BY WILLARD C. BRINTON,[1] NEW YORK, N. Y.

THE function of a ship is the transportation of passengers or freight between port cities. When a ship is in port it is not functioning.

For a steamship line in foreign trade or intercoastal work, approximately one-half of the budget is spent on terminal activities. The per diem charges for a ship can easily be segregated in proportion to the number of days the ship is at sea and the number of days in port. Interest on capital, depreciation, and obsolescence can quite readily be allocated. General administrated expenses may not be quite so simple to divide between operations at sea and port activities, but on any basis a large portion of administrative expense is properly charged to the ship in port.

The author would like to publish percentages of representative steamship lines in support of the point of view that terminal activities are such a large fraction of the total budget; however, the confidential nature of these figures makes it difficult to give actual data, and tabulations are therefore omitted.

The maintenance of continuous service of a foreign or intercoastal shipping line requires a number of ships. Operations are naturally on a large scale, and the annual budget of such a line runs into millions. It is surprising that the organization heads of steamship companies usually disregard the functional division between port activities and sea activities. They handle their port activities on a basis of line organization rather than of staff organization. The executive at the top whose scope is sufficiently wide to include all port activities is busied with many and varied problems affecting his corporation as a whole. There is usually no individual that makes a specialty of all these activities of port organization for which millions of dollars are spent yearly and which so greatly affect the success of the undertaking.

The superintending engineer or marine superintendent of a steamship line, or whatever his title may be, usually has had years of experience in his field. In general it may be assumed that he has reduced the cost of ship operations at sea to a point where it would be difficult for any further savings to be made on a specific ship for such items as fuel, lubricating oil, and repairs. It would seem that the men who have made these excellent records for the operation of ship machinery would be naturally the ones to improve the methods of terminal operation. However, they do not usually have authority over the terminal work and perhaps consider it somewhat beneath their dignity. There has been too much of a tendency to consider terminal work a matter of driving men through a labor boss with a vocabulary amply profane. Perhaps the idealism of the engineering-trained man has made him retire from pier work to what Kipling would call his steam gadgets. Whatever the cause may be, at the present time, there are relatively few men in the terminal operations of shipping companies with mechanical training, not to mention engineering education.

Practically all the problems of a ship in port are of such complexity that a trained engineering mind is needed for adequate solution. Ships should be designed with a definite relation to the cargo. In so far as possible the ships and piers should be designed together. Naval architects have given the port needs of ship design much less attention than is deserved. Yet during the last few years quite remarkable improvements have been made in ship design tending to increase the speed or reduce the cost of a ship at sea. We now have electric drive, geared turbine drive, Diesel engines, pulverized coal, and many other methods for greater speed or economy on the ocean. Recent increases in speed and reduction in fuel consumption at sea have so reduced the costs incident to sea operation as to make costs incident to port operations "stick up like a sore thumb." There is a fascinating interrelation between all the factors entering into the cost of ship operation—change any one and it affects others.

During the time that these recent engineering improvements in ship design were taking place there has been a constantly increasing wage rate for stevedoring. One ship operator has said that it costs more to put the cargo into a ship and take it out at the other end than to move it from New York to San Francisco. Of the port activities stevedoring bulks so large that any increase in wage rates or decrease in effectiveness of labor


THE "TEC" (TECHNICAL ENGRG. CORP.) TRUCK RESULTED FROM TWO YEARS' ANALYSIS OF PROBLEMS AT EIGHT PIERS

(Prime features are large loading area, short turning radius, lift mechanism for separable bodies, ability to operate rapidly in either direction, crane attachment instantly available.)

seriously affects the owner of a ship. The work of handling ship cargo is not only severely arduous, but the accident rate is disgracefully high. Compared with usual industrial operation stevedoring work seems unnecessarily crude. The men themselves must realize this and may be justified either in leaving the field entirely or in asking still higher wages to cover the muscular strain and the danger hazard involved.

For the last few decades ocean carriers have been largely controlled under foreign flags. Our intercoastal business dates only since the opening of the Panama Canal and was much upset during the World War. American terminals have in many instances been managed by men in the employ of foreign steamship lines, temporarily assigned to authority in an American port. These men were thousands of miles from home and have had difficulty in getting authorization from abroad for making innovations or expenditures at American terminals. Under such circumstances should there be surprise that progress has been show?

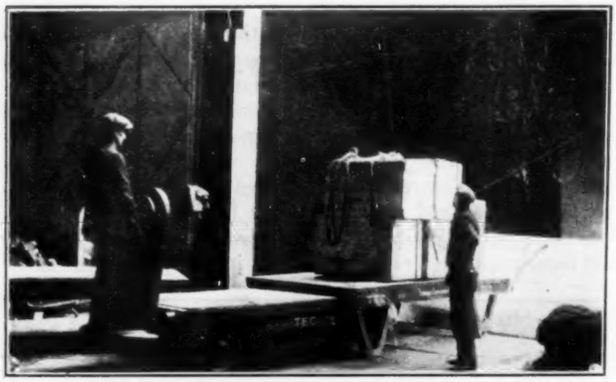
There is a more progressive spirit at Pacific Coast terminals than on the Atlantic Coast. However, the Pacific Coast piers are of recent construction, and the methods of operation have evolved according to the needs without being so heavily handicapped by precedent. But even on the Pacific Coast there is still almost unlimited opportunity for bettering terminal performance.

Americans may well be proud of their achievement in the han-

[1] President, Terminal Engineering Company, Inc., New York, N. Y. Mem. A.S.M.E.

Presented at the First National Meeting of the A.S.M.E. Materials Handling Division, Philadelphia, Pa., April 23 and 24, 1928.

dling of bulk cargo, ore, coal, grain, etc. But it is an easy matter to handle by machinery any type of uniform cargo whether in bulk or in packages. In the handling of package cargo there is little difference between operations in this country and abroad. The store-door delivery system, common abroad, is far in advance of our methods here for handling package freight at railroad terminals. Our railroad cars are so much larger than the cars abroad that shipments are accordingly larger here, and this makes the installation of machinery more feasible at steamship terminals where the wheels and keels meet.



By Placing Power Plant Below Level of Truck Floor There Is No Space Lost Except That Necessary for Driver

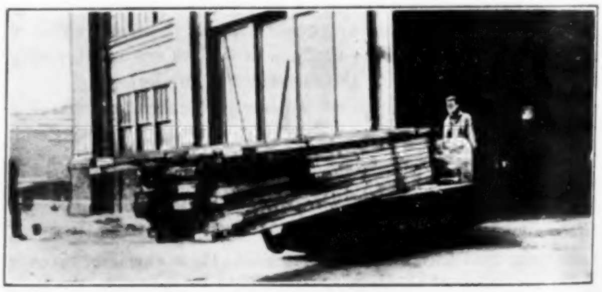
(The large size separable platform bodies permit handling more than one draft of cargo at a trip. The ideal is to have one steamship hatch worked by one truck.)

The problem of handling steamship package freight depends chiefly on the volume rather than on the weight of the goods involved. It is not at all difficult to build machinery to handle imported pig tin, lead, copper, etc. because the machines with ample weight load could easily maneuver in crowded quarters. To justify a power machine instead of the common hand truck it is necessary to have the power equipment carry enough volume of the bulky cargo to show an economical operation. The power-operated equipment on a pier has two major advantages over the hand truck in horizontal transportation; it can carry a heavier and more bulky load, and it can move it more rapidly. If in addition the power equipment can be supplemented with attachments that permit high stacking of heavy freight, there is great advantage on the side of the machine as compared with the hand truck.

The operation of loading a ship is more simple than discharging because sorting is usually involved in the discharging operation. A comparison of the hand-truck loading and machine loading of ships will be sufficient to indicate some of the fundamentals of the problem. It is customary to make up drafts of freight, each weighing approximately one ton. When hand trucks are used several hand-truck loads are necessary in each draft for the ship's tackle. Making up of a draft at the side of a ship causes congestion in a space only 10 ft. square. The effectiveness of the work in this small space largely determines the length of time the ship must remain in port. Also the bringing of various hand-truck loads to the side of the ship to make up a single sling load usually results in a mixing of the freight and breakage to the cargo, since the sling might include more than one type or size of package.

It is essential to bring drafts to a ship completely made up ready for hoisting and to take them away from the ship complete rather than in numerous hand-truck subdivisions. A complete draft of a ton or more is too heavy a unit to be moved horizontally by hand labor. If the management asks the average pier foreman to apply machinery and improve his methods, he is likely to begin by considering a tractor to pull the four-wheel hand trucks. The tractor sounds cheap and is often expected to work a revolution without any replanning of related equipment and conditions. Should a power tractor be used to pull completed drafts the combined length of the tractor equipment and the freight becomes serious. Also tractor equipment is not capable of backing out satisfactorily from blind alleys. Another point seldom thought of is that the ordinary four-wheel hand truck is not at all satisfactory as a trailer. Good trailers for pier use are expensive, and the combined investment of any tractor with sufficiently good trailers becomes much more than usually contemplated. In crowded quarters tractor operation is slower than lift-truck operation, and there is much more shaking off and damage to freight because of the vibration if trailers are not equipped with leaf springs and good rubber tires. If trailers are equipped with springs and rubber tires, the investment and the maintenance become large because of the great number of trailers necessary.

In 1912 and 1913, during some advisory work for the Bush Terminal in Brooklyn, the author had an assistant observe every type of freight handled on the seven large Bush piers each morning for a whole year. By this method there was a study of all the different classes of freight handled seasonally. It is believed that these studies are the most complete ever made of the problem of handling export and import pier freight. Tractors and trailers were thoroughly studied in service and proved deficient on the grounds stated. The following features were found essential for any type of equipment to handle the numerous classes of freight found on steamship piers:



Though Not Designed Primarily for Lumber, a Standard "Tec" Truck Can Handle 16-Ft. Lumber From Shipside to Pile

(Lumber is now so frequently a partial cargo that it is desirable to have one type of pier equipment handle both lumber and general cargo.)

1 Area sufficient for more than one draft of usual cargo
2 Smallest possible space occupied for a given volume of freight
3 Lift mechanism for use with separable platform bodies
4 Shortest possible turning radius
5 Quick acceleration
6 High speed with safety
7 Ability to operate equally well in either direction
8 Ample rubber tires and leaf springs throughout to give least shaking effect on rough floors
9 Legs of separable platform bodies to be opposite truck wheels
10 Ability to negotiate 20 per cent grades with loads to or from lighters or side-port ships
11 Tractive power sufficient to shift freight cars
12 Design arranged for pushing freight by sliding on pier floor
13 Automatic coupler so that lift truck can be used as tractor whenever trailers are of any advantage

14 Small fire risk for use through side-port ships
15 Ability to handle material 20 ft. or more long
16 Quickly attached power-operated accessories
17 Instantaneous crane attachment for lifting drafts made up directly on the floor
18 Low center of gravity to permit high stacking with crane attachment
19 Unit construction necessitating smallest possible number of different repair parts
20 Lubrication arranged for minimum attention
21 Ability to operate through city streets and over railroad tracks adjacent to terminals
22 Versatility sufficient to handle effectively any style of cargo worked on a pier.

Electric storage-battery trucks built on the foregoing lines have now had years of service on steamship piers handling practically every kind of freight that comes to a pier. A check of the principles has shown their correctness, and vast savings to shipping are possible by further application along proved lines.

The use of the crane attachment for a truck with an alternative set of lift bodies permits the working method to be changed if necessary every few minutes throughout the working day. Where the freight is light and bulky the lift bodies may take on one trip what might require several trips with the crane. If the material is too heavy to lift on the separable bodies—for instance, oil or chemicals in barrels—several barrels can be carried at one time with the crane attachment. If high stacking is necessary the crane attachment can save much human labor. Although numerous types of attachments can be applied to this type of electric truck, the handling of miscellaneous cargo requires that any kind of package be worked without too many different kinds of attachments and only one size of truck.

The technique of freight handling on steamship piers has been built up over a century or so of using the hand truck. The ordinary point of view is to use the hand trucks most of the time and mechanical equipment only on special jobs. This code is being reversed, and there are now some steamship piers on which a hand truck is seldom seen. The thing to do is to apply the


When Warehouses Are Located Close to Terminals It Becomes Feasible to Have Freight Move Directly From Steamship Pier to Warehouse

(The saving in rehandling and in pier congestion may pay handsome dividends.)

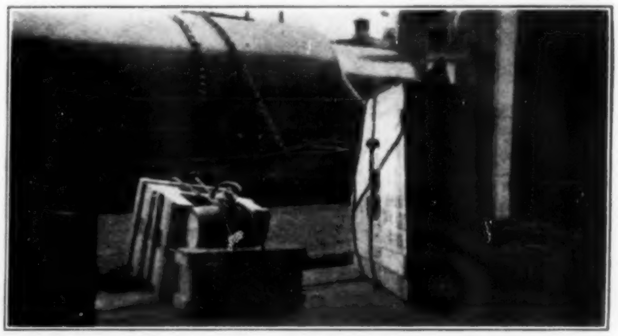
machinery and develop the right method for machine trucking for each particular class of freight just as hand-truck methods have heretofore been developed. The pier workers themselves are interested to make the work as easy as possible and in the aggregate will furnish many of the ideas for the ultimate best machine methods.

Ships have increased greatly in size during the last 15 years. Most ships tie up at piers built in an age of smaller ships and cargoes. As a result there is not enough space on the pier itself to hold the cargo. Either the ship must be moved, if the pier has sufficient length, or the cargo must be carried long distances lengthwise, piled high in the air, or some combination of these methods used. This factor of big cargoes has greatly increased the length of trucking distances and the height of piling. Distance does not make a material difference to mechanical methods, but it vastly increases costs if hand-truck methods are used. High piling is still done largely by hand because sufficient study has not been given to the application of machine methods.

Sorting of discharged cargo costs hundreds of millions of dollars yearly, and practically nothing is being done to remove the cause.


A Crane Attachment Which Automatically Locks to the Truck Is Picked Up Whenever Needed

(By applying different methods or attachments the Tec truck can be quickly adapted to any type of cargo.)



When Loading a Steamship, Drafts Should Be Brought to Shipside Already Made Up

(By bringing the drafts to shipside already made up several drafts can be accumulated ahead of the ship's winches.)

Fundamentally, sorting is due to the small size of the packages of freight. Packages have been made man size rather than machine size. The chief difficulty in sorting lies in the lack of cooperation between the loading and unloading organizations at the two ends of the ship's run. Ships are often scheduled to stop at many ports, and the sorting involved at the point of discharge is a composite of the loading methods at all points of origin.

Unless some one man or group of men is constantly studying this situation, unnecessary costs owing to sorting of cargo are sure to result. Of course not all cargo can be stowed simply, as it is frequently necessary to pack the smaller packages between the larger cases of machinery. Because of the diversity of the American manufactured products there are all kinds of sizes and shapes exported. Typewriters must be loaded with locomotives. Discharging a cargo of diversified manufactured products is justifiably more complicated than the handling of the

raw materials imported into this country and discharged at American ports. We should be able to improve greatly on the methods of discharging in this country since much of the inbound freight comes in large lots of one size or kind of package.

Where the packages are all of one size or shape it is the sorting according to the identification mark on the packages that causes tremendous confusion, delay, and expense. If the packages are not stowed in the ship so that packages of one mark can be easily segregated, then the drafts from that ship may seem to contain even more marks than there are packages. Labor is cheaper in all other parts of the world than it is in this country. Every steamship operator should wage an increasing campaign to see that cargo is so loaded at foreign ports that it can be most cheaply and quickly discharged here. One prominent freight line has recently reduced its American direct costs of discharge approximately 20 per cent on an average of six months as compared with the preceding six months. This was done chiefly by proper stowage on the ship by which freight was put into blocks according to the marks. With the block stowage it is possible to make up drafts inside of the ship so that they may be hoisted out one mark to the draft. By using larger drafts and machinery on

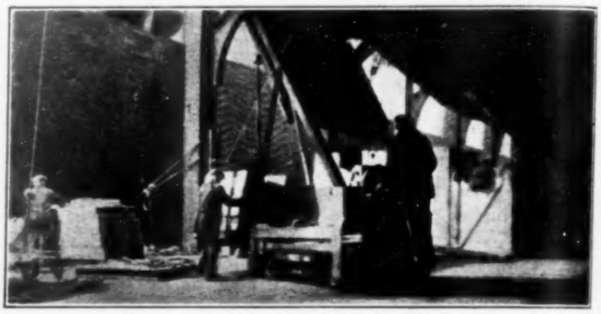
Block Stowage of Cargo Inside Ship Permits Taking Directly to the Pile Full Drafts of One Mark

(A special sling arrangement allows the use of larger drafts and the sling can be so picked up by the crane as to avoid slack of the sling rope and permit machine piling as close as possible to ceiling of the pier.)

the pier it is a simple matter to get the freight directly to the proper pile on the pier as the whole draft can then go to just one pile. Freight is high in the air when it comes over the side of a ship. The higher it is carried by power trucks across the pier the smaller the amount of labor required to stack on the pier.

With proper study there would seem to be no excuse for the continuation of hand-labor methods for sorting bags of coffee, bags of cocoa beans, castor-oil beans, etc. Practically all the coffee arriving in New York is "humped" by men carrying 130-lb. bags on their shoulders. Coffee is so mixed in the ships that a postoffice operation is required to sort each bag to its place on the pier.

Even though cocoa is loaded on the African coasts in surf boats where men wade out through the water to these boats with one bag at a time, there are possibilities for getting the freight into the ship so that it would not be necessary for men to carry each bag in America where the longshoremen get 85 cents an hour with time and a half for overtime. As many as 70,000 bags of castor-oil beans have recently arrived in New York on a single ship



Trucks With Crane Attachment Carrying Full Drafts on Aeroplane Slings

(Cranes supported on the pier structure cannot work outside the pier shed or cross over easily from one aisle to another.)

hopelessly mixed in the stowage. It is not easy to engage men who are able to carry these heavy bags of 160 lb. each. Certainly the men themselves would respect their employers more if the employers made the work simpler and easier.

A rope sling is commonly used in handling bag cargo. The rope sling remains today in the same form as it was when man first put freight into ships or developed rope manufacture. If a draft of bags or other materials is taken from a ship in a rope sling, the draft tends to fall apart the moment it reaches any support to carry the weight. For a century or more pier workers all over the world have attempted to catch the draft at the moment of its landing and so hold the sling rope as to keep the draft together. Some such method is necessary if drafts as a whole are moved away from the ship direct to a pile. There has been great loss of time and breakage of freight due to the drafts falling apart while being moved on the pier. This is particularly true when drafts are placed on trailers without springs or rubber tires and moved at high speeds. Then, too, the falling apart of the draft often causes smaller drafts to be used in an attempt to remedy the condition.

There recently has been developed a device known as a sling "tek" which can be placed on any rope sling to make it automatic. The sling tek slips to the tightest position and holds the sling at that point. When desired the locking cam is quicky released by hand or foot pressure. Larger drafts are possible and drafts can be landed more quickly, since there is no possibility of their falling apart.

Another economy feasible by this device results from the ability to carry all drafts of any kind by crane equipment by merely hooking the crane directly to the tek, thereby eliminating the headroom usually required by the long end of the sling. This point is important because it permits the use of pier machinery to pile the drafts where with the long sling there would not be sufficient headroom to make mechanical piling effective.

In many parts of the world ships must still be loaded from lighters. It is difficult to make up the drafts with the lighter

pitching in rough water, and the ship itself is likely to be delayed. A simple hoist on the shore might lift whole drafts to or from lighters. Wherever lighters are used there is a possibility of equipping each lighter with a quota of non-slipping slings to obviate the rehandling of separate packages at each end of the lighter movement.

Some one who has the proper inspiration could make a fascinating study as to how the many commodities in foreign commerce happened to become standardized in the various odd sizes, shapes, and weights of packages for each article. But more important would be a study by the United States Department of Commerce as to the possibility of recommending changes in the packages. Consider plantation rubber from the East Indies. This huge commerce has developed within the last few years. The material is so valuable that each package is checked and rechecked. There might be as many as 100 separate clerical

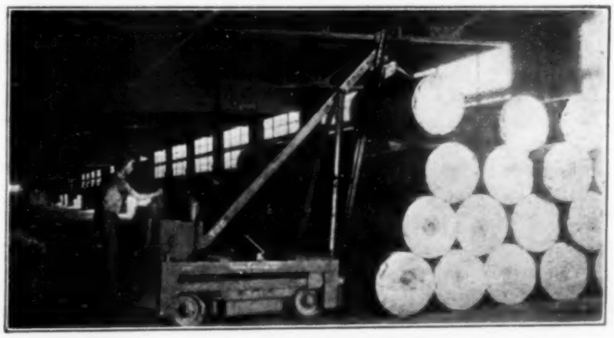
LARGE SHIPS FREQUENTLY CARRY CARGOES TOO BIG FOR PIER AREAS AVAILABLE

(The use of mechanical equipment at terminals facilitates handling freight over large adjacent areas. In the illustration above Spanish olives were sorted over acres of sand fill adjoining the pier. Carrying the 1500-lb. casks instead of rolling them eliminates the opening of seams and lessens the spoilage due to leaks in the casks.)

transactions in the history of any case of rubber from the time it obtains its identity to the time its existence ends in a rubber mill. Why did it happen to be a nearly cubical package with six faces, any one of which might contain the elusive identification mark? The weight, around 220 lb., is heavy for Malay physique and is too light for effective machine operation. If rubber were packed in packages of 1000 lb. or even 2000 lb., sorting would be simplified, since power equipment could readily take each package to its proper pile and quickly stack it as high as desired. Larger packages would automatically reduce not only the danger of theft, but in the ratio in which the packages are made larger, reduce clerical work, weighing, sampling, etc.

How did it happen that in this same East Indian territory burlap has long been shipped in large bales weighing from 1000 to 1500 lb.? A package of this kind is large enough to be economically handled by machinery carrying one package at a time directly from shipside and tiering on the pier 12 ft. high with negligible costs for the tiering. Burlap was formerly one of the difficult kinds of freight to handle because the longshoremen complained of the weight of the packages. They could not tier the bales high because it was impossible to get enough men around any bale to elevate it. Today with machinery burlap bales are ideal freight to handle, and the handling cost per ton is lower than for almost any other commodity. Another good type of package for mechanical handling on piers is newsprint paper in 6 ft. rolls weighing about 1300 lb. each. By special attachments on electric trucks this paper has been handled from shipside at the rate of from 40 to 50 rolls per hour per truck, sorted and stacked four rolls high on the flat, without a human hand touching the paper after landing on the pier.

Customs weighing of imported cargo by the Government employees has long been by antiquated methods with great expense



CARRYING AND STACKING 1300-LB. ROLLS OF NEWSPRINT PAPER

(An attachment for the Tec crane permits each truck operator to transport and stack 40 to 50 rolls per hour. No helper is needed.)


AUTOMATIC BURLAP-CARRYING ATTACHMENT FOR TEC CRANES

(This burlap attachment can be put on in a few minutes. It automatically grabs a bale of burlap and allows horizontal and vertical movement for stacking three bales high. One operator can handle 60 to 70 1500-lb-bales per hour.)

and delay. If mechanical equipment is used there are many possibilities for moving the freight over scales in the course of the regular operations, thus eliminating rehandling and consequent delay to valuable freight. It is only within the last year

that sugar going into public warehouses in the port of New York has been weighed in 3-ton lots by running electric trucks over the scales. The amount of sugar stored in New York alone may be 200,000 tons in a season. The engineering side of weighing is not difficult. It is chiefly a matter of organization to apply the engineering principles.

Better design of ships from a cargo standpoint may result in making many ships almost obsolete within the next few years. The problem has been so little studied that it is impossible to foretell the nature of the changes. Whatever they may be

Burlap Bales Stacked Three High on End

(It would be impossible to stack these heavy bales this high without the use of mechanical equipment. Not only is the time of the ship saved by moving the bales more rapidly but the capacity of the pier is doubled.)

however, it is pretty safe to predict that they will be revolutionary.

The new *California* of the Panama Pacific line, the biggest merchant ship built in American yards, has numerous side ports large enough to take a sedan car. Electric trucks can be run through these side ports without any objection from the underwriters who might not allow gasoline equipment. A side-port ship having large hatches might be equipped with elevators so that electric trucks can take the package freight directly to the proper part of any deck of the ship for stowage. This obviates the necessity for placing freight in slings just to get from one deck level to another. It might be desirable to have an elevator cover only half of the hatch area and use a hoist mechanism for the other half, so that the elevator hatchway itself may be filled with freight after all other portions of the ship are stowed.

Much bulk grain is loaded while ships are at general-cargo piers. Trimming the grain has been an expensive and time-consuming operation. Mechanical equipment for trimming grain in ships is now available and should be more generally used. Again it is a matter of organization, because of the divided responsibility between the grain elevator crews, the shipowner, and the contracting stevedores. Grain is often handled in tramp steamers, and the ship's agents seldom understand the possibilities of mechanical trimming.

Ships in foreign trade are on such long runs that they cannot be operated on any schedule which will keep the terminals continuously busy. Ships will bunch at the terminals no matter how carefully they are timed, and there are sure to be days or even whole weeks without any ships whatever at a given pier. Even the largest shipping companies would hesitate to purchase enough mechanical equipment to load or discharge all their ships that might be in port simultaneously. They could perhaps provide for their minimum or even their average requirements, but not the maximum. Then, too, it is not only a question of investment in equipment but of having enough highly skilled operators available when necessary. The effective operation of marine freight-handling equipment requires men of a quite unusual type. Unless these men are given sufficient continuous work they will drift away to other industries.

Commercial stevedores are paid on a tonnage basis, and it would be supposed that they would have the incentive to develop or buy the best machines for handling marine freight. Stevedores have, however, been at a disadvantage in that they have usually had too little certainty of continuing the business with any single ship owner. It has been too big a risk for them to invest in sufficient mechanical equipment to do work on an all-machinery basis.

The best thing that can happen to a ship owner's bank account is the elimination of the hand truck from his piers. There seems to be no likelihood of sufficient mechanical equipment at steamship terminals to banish the hand truck except by a rental service. Versatile mechanical equipment must be mobilized in sufficient quantity at any pier as needed. This requires rented freight-handling machinery with professional skilled operators.

Much of the miscellaneous gear used by steamship lines or by contracting stevedores is unfortunately not of the best design for the purpose, and therein lies opportunity for men with engineering training. The average longshoreman cannot be expected to select the one best method for the various kinds of freight which change every few minutes during a working hour. When power trucks instead of hand trucks are used on a pier the truck operators can be of tremendous value by using their greater mechanical experience to guide all the other men in the gang. When the hand truck is eliminated, old habits of work disappear and there is a zest in the job which creates new performance records

Pacific Coast Timbers Are Too Large and Heavy for Man-Power Handling

(By use of mechanical equipment these timbers can be easily moved rapidly.)

without conscious effort on the part of the men most intimately involved.

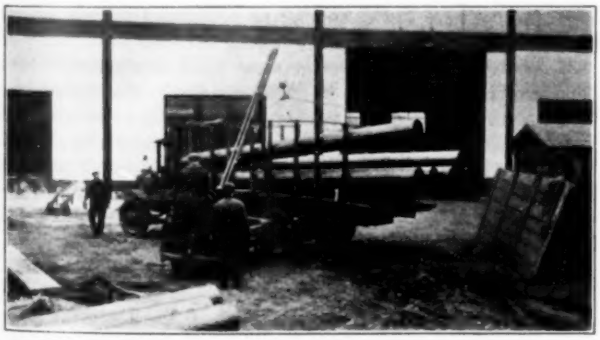
Mechanical freight-handling equipment should move at speeds three to five times that of hand trucks. Usually first installations of machinery on steamship piers use the power equipment on only one or two hatches of the ship. If the other hatches are worked by hand trucks, power equipment can travel no faster than the hand truckers using the same aisles. Mixing the methods is unnecessarily dangerous for the hand-truck pushers and it does not give a fair comparison with the machine methods. Until all pier operations are done by machinery without any hand trucks to get in the way and slow up operations, full economies will not be realized.

Overtime wages at 50 per cent increase are watched most carefully in the offices of ship operators. Not only does the cost per

ton go up because of the overtime wage rate, but there is a decrease in the tonnage because the men become tired from long hours of work. Machinery does not get tired and can work at high efficiency all night. There is an advantage in working many of the busy terminals at night because at night there is freedom from the congestion of motor trucks, taxicabs, etc. Few ship owners realize that power trucks on the pier need cost no more for night operation than for day operation. Although the truck operator may get an extra 50 per cent wage rate at night, the reduction of overhead charges on mechanical equipment offsets the overtime wages. So far as the pier operations are concerned, a look into the future seems to indicate regularly working all around the clock. Ships are getting so much larger and more expensive that quicker turn-arounds are sure to be demanded. A ship is active all of the 24 hours when it is at sea; why should it waste so much time in port?

Until recently operations on steamship piers rather than inside the ship have determined the speed of loading or discharging cargo. This has been owing chiefly to the assembling and disassembling of cargo drafts immediately at the side of the ship. Where mechanical equipment is used to bring full drafts to the side of the ship and take them away from the shipside, the whole pier operation is changed. Mechanical equipment on the pier throws the weak spot of cargo handling to the inside of the ship itself. Stowage of miscellaneous cargo is at best highly complicated, and every possible attention should now be given to this phase of the work. The naval architect will be needed to assist in transforming ships so that the cargo inside the ship can be handled with more dispatch and less muscle.

Ship terminals have mostly been designed by the civil engineer whose chief thought has been the under-water construction. The upper portion of the pier, which affects all of the cargo handling, has received relatively little attention. All concrete and steel design for the freight section of any pier should be planned around the mechanical-engineering features. It is practically impossible properly to fit the mechanical engineering into the

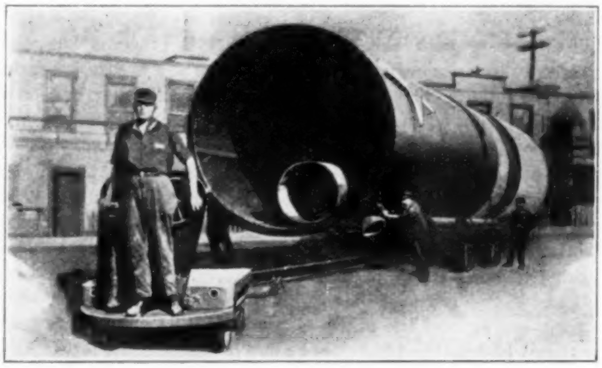


TERMINAL CONGESTION CAN BE RELIEVED IF IMPORTED FREIGHT IS TAKEN AWAY FROM THE PIERS PROMPTLY

(There is also a reduction in the accident rate if heavy articles are lifted by machine methods.)

civil engineering after the terminal is completed. Take for example the matter of elevators for two-story piers. These elevators are seldom large enough and they are often so spaced as to cause unnecessary congestion in freight handling. In ports where lighters are used, piers should be equipped with ramps to permit running electric trucks on and off lighters; proper location of such ramps requires in itself very nice study. Many piers are built with outside aprons so narrow that throughout the whole lifetime of that pier there will be unnecessary labor and delay for freight handling and excessive damage to cargo.

The use of mechanical equipment at steamship terminals permits taking the freight any reasonable distance without increase in cost. There is nothing to prevent piers being made 600 ft. or more wide. Also power equipment permits carrying freight immediately away from shipside for storage in any nearby area. In New York City 5000-ton cargoes of Holland or Belgian brick are regularly transported and piled in spaces perhaps one-quarter of a mile from the pier berth. Also cargoes of Spanish olives in barrels or hogsheads are regularly sorted over several acres of sand fill adjoining the pier. From an engineering standpoint



SHIP OPERATION FREQUENTLY REQUIRES THE HANDLING OF LARGE, HEAVY MACHINERY.—INDEPENDENT FOUR-WHEEL DRIVE OF THE TEC TRUCK GIVES GREAT TRACTION FOR PULLING OR PUSHING HEAVY PIECES

(The varied types of work shown in the preceding illustrations are chiefly of interest in that they have been handled economically by one model of Tec truck with a few attachments which can be instantly applied.)

it is perfectly feasible to take large lots of cargo directly from the ship to any floor of nearby city warehouses. Thus if ships have large side ports and elevators, Pacific Coast canned goods can regularly be moved directly from any portion of any ship deck to any part of a nearby wholesale warehouse.

The same ships and the same men in the crew are involved in each end of a ship's run. This is entirely different from railroad operation. It should not be so difficult to get freight put into a ship at one end so as to get it out of the ship properly at the other end. Coolie labor is low in cost, but expensive for supervision. Use of mechanical equipment in tropical ports is often justified on the ground that less mixing of cargo gives a large saving at the American ports.

Longshoremen in this country cannot be expected to do the heavy cargo handling work that they did in former years. As the saying on the Atlantic Coast goes, "In the old days we had wooden ships and iron men, now we have iron ships and wooden men." It is up to the ship owners to change the working conditions. A contracting stevedore cannot do it alone, because he has no control over the loading of cargoes in ports other than the one in which he is the contractor.

The high accident rate and great insurance expense should be sufficient to get the ship owner's attention. It has been proved on the Pacific Coast that most marine accidents can be eliminated by competent engineering study. Accident-prevention work alone is sufficient justification for more engineering-minded men at ship terminals. The use of more machinery and less hand labor is definitely known to reduce accidents. Reduction of accidents automatically gives better economic cost.

Men properly qualified to make improvements in ship-terminal operation do not exist in any great number. The question of getting results is therefore a very real one. Perhaps the easiest way to make a beginning would be to have carefully picked men put in training for this work and serve first on a purely staff basis, reporting directly to the general manager. In this way

there would be no upsetting of the authority of the pier organization responsible for turning the ship around in the least time and at the lowest cost. These special men should be given every possible encouragement from the top officials of the organization. They will need it, and unless they get it they may leave the shipping field and set back the whole effort to an entirely new beginning. Unfortunately there are too few general managers who themselves understand the terminal problem sufficiently well to advise and back up these selected men during the period necessary for them to become familiar with all phases of the work.

Connection with the general manager's office is suggested primarily because only at the top are there any cost or statistical figures available to stimulate imagination and spur one on to making further studies. No two cargoes are alike and the business may change entirely at different seasons of the year. A rough and ready ability to think in terms of statistics is desirable. A beginner should be warned, however, against trying to prove too much by cost figures or even the simplest motion studies. The operations are usually so crude that the problem becomes primarily one of judgment and ingenuity. A valuable process for quick test purposes lies in comparing two methods by balancing one against the other, factor by factor, and quickly ascertaining which method has one or more predominating advantages. After some experimenting the investigator will gain confidence in his own judgment and know almost instinctively when a freight-handling operation is moving properly without using a stop watch or other timing methods.

Marine-terminal work is more than usually interesting, and there should be no difficulty in getting the right type of men to enter the field if they are assured proper cooperation and support. There is a need for more men who speak the language, which need not necessarily be profane.

## Discussion

H. E. Stocker.[2] I think that the author is working along the right lines, but disagree with him on lift trucks as compared with tractors and trailers. The thing that interests me is that a tractor can haul a train of trailers for long distances on a pier, 1500 ft. long for instance.

An important point is the coordination of mechanical equipment, whatever it may be, with the remainder of the operation. There is some inclination on the part of terminal-operating steamship men to buy, say, four or five lift trucks and the necessary number of skids and shove that equipment into the operation without a comprehensive study of the operation so as to get the maximum advantage from the new equipment.

As the author says, shipping has not kept pace with manufacturing. Shipping management has not developed as rapidly and as comprehensively as manufacturing management.

In shipping we need more of an engineering viewpoint, and with that there is bound to come a greater development of mechanical handling. Executives for the most part are not trained in the management principles that have done so much for manufacturing. If that is done it will undoubtedly bring a revolution in shipping and make it possible for American ships to reduce to a large extent the handicaps encountered in competition with foreign shipping.

Recently in Chicago I saw the operation of the Goodrich Transportation Company, and the same day I saw the operation of a manufacturing concern where they keep the material on wheels or the equivalent. The Goodrich Transportation Company applies that same principle. They receive the freight on trailers for the most part, keep it on trailers until it is pulled into the ship through side ports, and leave it on trailers while being transported to its destination point.

The principle of standardization can be applied in shipping to a very large degree. I have been on piers where they used two or three kinds of equipment to handle exactly the same class of cargo. One of those is the best, or there is some other class of equipment on some other pier that is the best and that certainly should be used in every instance.

The author is on the right track. We need more men in shipping who will approach the cargo-handling problem from the engineering viewpoint. It will be a substantial step forward if shipping men can be induced to join societies such as The American Society of Mechanical Engineers as associate members. It will be a step forward also if the Society will take a greater interest in shipping problems. Papers of this nature do much for shipping and widen the field for mechanical engineers and for manufacturers of mechanical equipment.

R. L. Lockwood.[3] To a certain extent these questions of standardization that the author has brought up have been put up to us, but so far the work done has been confined almost exclusively to domestic shipping problems and to domestic containers, and there has been very little done with export containers and nothing at all with import containers, except imports from foreign branches of American companies. There is a little work going forward on that.

Recently the question of standardization of lift trucks and skid platforms to secure interchangeability at both ends of the line has been brought up to us forcibly by many shippers, by at least three railroad companies, and by a number of manufacturers. It is too early yet to make any statement about what will be done.

We realize that the matter of shipping on skid platforms, either "live" skids or "dead" skids, is interesting manufacturers of many different commodities. Some motor-car companies are demanding that certain goods be delivered to them on skid platforms. There are a number of companies owning several plants that make a practice of shipping between those plants on skid platforms. They have the same truck equipment at both ends and can easily handle it. The savings by that method are said to have been large. One instance was in paper shipment and another one of pulp. The saving in material alone with a temporary nailed skid platform has run as high as 77 per cent as compared with the cost of shipping in packing cases. Loading on a skid platform and loading the platforms into a railroad car instead of packing the goods in cases and loading them in a railroad car has shown as much as 90 per cent saving in labor. One railroad system is using skid platforms and lift trucks for handling railway stores between different stores points on its own lines. Figures indicated that in one year they cut down the number of cars in that service almost one-third, and made a cut in labor cost of about 65 per cent. J. V. Miller, who is assistant general storekeeper of the St. Paul Railroad, has been particularly active in that work. In a recent article he made a statement that I think sums up the materials-handling situation from the viewpoint expressed by Mr. Hagemann; that handling materials, as distinct from transporting them, adds to cost, but adds nothing at all to value. Any gain made in cutting down the cost of mere handling of materials as distinct from transportation is a net gain.

The Division of Simplified Practice is now gathering information from railroad companies, shippers, and manufacturers of equipment, and within a few months, judging by the progress

[2] Munson Steamship Line, New York, and McCormick Steamship Co., San Francisco.

[3] Division of Simplified Practice, Department of Commerce, Washington, D. C.

in the last two or three months, we shall have a mass of material available.

It has been suggested that we make a number of studies of the possibilities for standardization of skid platforms, with the idea of determining certain national standards of dimension, particularly the clearance height under the platform, so that all kinds of lift trucks can handle the same platform; the width between runners or legs of the platform; and the overall length and width, so that such platforms can be loaded economically into a railroad car. The St. Paul people developed a size of platform that can be loaded lengthwise in a 50-ft. boxcar, three platforms wide and four rows deep to the door, making 12 platforms, and then 12 on the other end. By this arrangement they can get a larger proportion of capacity carloads, whereas formerly the average carload in that service was very much below capacity.

The necessity for fitting standard skid platforms to a railroad car is of course of first importance. There are therefore three points to be considered. Apparently the clearance height of the platform affects more different kinds of equipment than anything else. Perhaps the width of the platform between runners is next in importance, and then comes the overall length and width to fit into a railroad car. That is as far as we have gone. We all realize that this problem extends into almost every field of manufacturing and shipping, other than the handling of bulk cargoes. There are thousands of commodities that are handled now and that have been handled for years in and around plants on skid platforms. Very few have been handled between plants or on railroad shipping platforms. That practice is growing very fast. In order to avoid chaos as it continues to grow, it will be necessary soon to have interchangeability of equipment. The same conditions are developing in this as developed years ago in the railroad business, when interline use and car exchanges began, and the necessity for interchangeable couplers, standard gage, and other standard features of railroad equipment became evident. Today such standards are accepted almost as a law of nature, but they are actually results of cooperation. The same sort of cooperation between shippers, railroads, and manufacturers of equipment must be secured before such results can be accomplished in connection with lift trucks, skid platforms, and similar equipment.

The Department of Commerce will cooperate in every possible way to that end. It has been represented to us that the direct cost of shipping materials which can be handled on skid platforms from shipper to consignee runs from seven hundred to eight hundred million dollars per year in this country. Savings made by shipping on platforms in certain instances have run as high as 90 per cent in labor and 70 per cent in material. Estimates run from a possible saving of 10 per cent to 50 per cent on the enormous figure mentioned, but as yet we have been unable to verify the figures. It is all up to the industries directly concerned, and the matter is being seriously considered. We are going to do everything we can to help it.

C. B. Crockett.[4] Would the author care to discuss the inherent possibilities of the dead skid and the live skid, and the question of taking material from steamships, particularly sideport operation, by the use of the lift truck, where it is possible in most cases to get a skid load for one consignee but the very next skid load may be for a different consignee, and the ultimate placing of that widely separated material. Is it possible to work out a method by which lift trucks can take the material from the ship on live skids and so classify them that they may be taken down to pier by the tractor trailer method and dropped off at the proper destination? The question in a great many cases, as I understand it, is that the use of live skids is dependent upon the rapidity of movement of the material and how long it has to be stored.

One of the New York Central engineers recently said that they would like to use live skids, but that the investment was too high because they had to keep the material on the pier sometimes for as long as 28 days. They are therefore using the dead-skid method. The author has had experience with the use of the two methods and might explain the limitations of both the dead and the live skid.

[4] Society for Electric Development, New York, N. Y.

### Author's Closure

Mr. Andjeski, of the Cleveland Terminal Railway, inquired about the capacity of that truck and the speed with which it operates. It is of 3 tons' capacity and runs 10 miles an hour empty and about 8 miles an hour loaded. The speed can be made higher or lower if desired.

I shall answer the questions of Mr. Crockett and Mr. Stocker together. Mr. Stocker asked regarding lift trucks and trailers. I hesitate for fear some of my friends in the tractor-trailer industry may misinterpret my remarks. Trailers in this class of service on piers ordinarily are not larger than 3 x 6 ft. That size will not take more than one draft of ship cargo. The principle I have been working on has been to put freight on a lift platform. I call it a separable body, for it is not a skid, and the word "skid" is a misnomer. The word "skid" originally meant something like a machinery skid that had continuous members instead of legs as a support for the platform. We have mostly outgrown the skid type of lengthwise member, and we have placed legs on the corner of the platform. I believe the word "skid" is unfortunate and should be dropped.

Now if a load were put on a lift platform, or separable body, as I call it, the speed of movement can be increased because of traveling on rubber tires and springs. I want to bring out that point in different ways because otherwise I might not make myself clear. Taking steamship operations and terminal operations, there are seldom more than two or three trailers used behind one tractor. It is possible to put a dozen trailers behind one tractor but they are not seen that way in actual practice. Many times one will see just one trailer running behind a tractor. I doubt if the average exceeds two. Now suppose we put upon a lift platform as much freight as can be placed on two or three trailers. It can be run at higher speeds. It can back out of a blind alley. The goods will not shake off. The platform is cheaper for a given volume or weight of freight than the combined two or three trailers to take the same goods. That is indicated in the methods of the New York Central Railroad where they want to hold the goods temporarily. I consider these lift-truck bodies as sections of a floor of a warehouse or pier. Let the goods remain on the platforms as long as they possibly can. It then comes down to the quite simple problem of the cost per square foot of these platforms, sections of a floor they might be called, so as to permit as far as possible the leaving of goods on the platforms until they must go through the next process.

In Seattle recently a prominent shipping man was mentioning the handling of raw silk from China. It must be inspected by the customs officials between the time it comes off the ship and goes into an express car. Special trains are run across the continent to New York for this silk. He asked, "Why lay it on the floor for customs inspection when you are moving it on special trains across the continent? Let it remain on the platforms until inspection is completed." I think there is no question but the next step is going to be the using of platforms in quantities so as to save a handling or two of the goods. If merchandise can be left on the platforms for customs inspection and weighing, taking care in sorting to have one lot on one platform, as far as possible, the deciding factor then is the cost per square foot.

The speed of the tractor and trailer on piers is usually slower than that at which lift trucks are being run. The speed of a tractor and trailer is comparable, perhaps, with the speed of the usual indoor lift trucks. The lift truck shown in the paper has 50 to 100 per cent more speed than any lift truck of which I know. That speed can be used if there is ample power and a spring suspension and if there is enough rubber in the tires. There is twice as much height of active rubber in these tires as is in the standard tires on what we might call indoor lift trucks. The old S. A. E. industrial-truck-tire standard was for 2 in. high including the metal base. The metal base was about $^1/_2$ in., the hard vulcanized rubber about $^1/_2$ in., leaving 1 in. of live active rubber. I accepted the outdoor S. A. E. tire standard of 3 in. total height. The metal base and the hard rubber are the same, but there is 2 in. of active live rubber. This gives a possibility of higher speeds over rough floors or rough ground.

The tire heights for street trucks are somewhat different now because higher tires are being made, so that the tire standards are all mixed up so far as street trucks are concerned. I am making the comparison as giving some possibilities for running at high speeds. Tractors and trailers ordinarily run at a lower speed on a steamship pier than do lift trucks because goods must not be shaken off. Also with the trailers, even those of the best design, there is difficulty in steering at higher speeds so as to not hit any piles of freight on the pier.

As to the question of live and dead skids: putting anything in the nature of castors on skids very greatly increases the first cost. I have designed some castors, better than anything I could buy, to get more ruggedness and better bearings, so as to make it possible to push a 3-ton load on the lift platforms illustrated. The conclusion I have reached in my own studies is to handle everything possible by machinery. With castors there is an implication that the skids are going to be pushed by hand. I say, do not push by hand; move by machinery. That involves sorting on the discharging end, if possible, inside the ship. Load merchandise so that when discharging it is not necessary to sort it outside the ship; do it inside. The stevedores may say that this cannot be done. I can show great savings by companies that are doing it. The stevedore who has to discharge ships usually does not control the loading at the other end. When he loads an outgoing ship at his pier he says, "Let the other fellow worry. My job is to get that ship out on time. The other fellow has to discharge the freight. I have loaded it so that it will not shift inside the ship. That is my job, to stow it safely and get the ship out on time." That is typical all over the world. If we get the goods out of the ship the right way, we should not put castors on skids or platforms, but we should use machinery. I try to put it to my men in this way; "If we were going to heaven, and going to handle freight in heaven, how would we revamp our methods?" And we reckon the ultimate in heaven and seen how close we can come to it on earth. I believe the use of castors on a steamship pier is a step in the wrong direction by which we are likely to set precedents that we shall want to change later. If castors are used, people will expect to push by man power for the next ten years. Don't do it. Let's move freight by machinery, and if we can't move it by machinery under present conditions, let's change the conditions.

John A. Grove, of the Atlantic Refining Company, has asked if there is any satisfactory means, other than by the winches and slings, of handling mechanically a uniform package to the interior of vessels without side ports, such as by a booster conveyor or spiral conveyor taking the package to the stowing point. That is a very interesting question. Side ports on steamers are worthy of a discussion by this Society. On the Pacific Coast last fall I found that the *H. F. Alexander* was built with side ports with the expectation of running coastwise on the Pacific Coast. Perhaps the insurance underwriters took literally the word "pacific" and thought it was all right to have side ports of large size on the Pacific Ocean. During the war the *H. F. Alexander* went across the Atlantic. The underwriters had no choice but to try it out, and there was no trouble, so I believe that this is the beginning of the acceptance of large size side ports on steamers running in what might be called foreign trade.

Intercoastal might be classified as foreign trade so far as the nature of territory you have to go through and it may be a valuable precedent. The new *California,* built by the International Mercentile Marine for intercoastal work, has large-size side ports. They are 8 ft. high and 8 ft. wide. That is high enough to run in any kind of rubber-tire freight-handling equipment. If this can be done in intercoastal service, I do not see why it should not be done in the Atlantic service. With side ports, as on the new *California*, there are beautiful passenger decks, with only one or two hatches on the whole ship made for large cargo. I am not speaking now of a ship to take locomotives, freight cars, and things like that, where the hatches must be big enough to take in long freight. I have seen the *Luckenbach* take 78-ft. long sheet steel piling for a drydock, pick them up, and lower them into the hold. For that there must be big hatches. This suggests another line of attack. Make the hatches so big that they are nearly all hatch, and then each draft can be set down where it is wanted.

There are several lines of attack on the freight-ship problem. The naval architects and ship operators should get together, and the mechanical engineers can help. There are so many different lines of approach that I do not know which one is going to be the answer; it depends on the particular trade. I believe that many ships now in use will become obsolete because of their cargo-handling cost as soon as they will be from the standpoint of obsolete engines. The field is practically untouched now. The side port has possibilities. I do not know what the underwriters are going to let us do about it. The Clyde line and different coastwise companies have been using side ports for years. Whether the word "coast" has any influence on the underwriters I do not know, but I believe with that precedent we can get side ports. With side ports the sling can be eliminated, and freight can be stowed in carload lots, inside the ship in such a way that there is a whole carload in one block. If the ship-loading crews do not stow it so that a carload can be found inside and if they do not bring the lot out intact on the pier, then somebody should be called "on the carpet" before the general manager. Canned goods may be loaded in such a way that they can be discharged to the pier intact as a carload when they come out. If it is necessary to sort according to the size of the prunes, or whatever it may be, at this end of the run, it is only necessary to sort through the area taken up by one carload, which can be done by hand. The freight does not have to be taken from one area to the next in this kind of sorting. If one would sort freight properly, he must stow the ship properly; in that way no castors or wheels of any kind will be needed.

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# The Hydraulic Handling of Ashes

By ARTHUR MELLOR QUINN,[1] PHILADELPHIA, PA.

FUNDAMENTALLY, the handling of ashes by water has long appealed to the practical designer and operator of boiler plants as offering a means of carrying the refuse material without the use of conveying machinery. For years mine operators have pumped water from the mines, leading the water beneath the boilers, discharging ashes into the stream, whence the mixture flowed to low-lying ground or was allowed to discharge into a discarded mine shaft.

The absence of machinery, the elimination of labor, and the fact that the ashes are handled cold and dustless lend a powerful appeal, but these inherent advantages, until recent years, have been largely offset by serious objections.

Most plants are not as favorably situated for the process as were certain coal operators: thus they have no continuous stream of waste water in sufficient quantities and under enough head to carry ashes. If they have, they have no place to which the ashes may be washed. Large modern boiler houses cover considerable area, the boilers are in comparatively long rows, and a stream of water with sufficient pitch to maintain the required velocity means placing the boilers very high above grade. Thus a sluice channel having a pitch of $^3/_8$ in. per ft. will maintain a water velocity of about 12 ft. per sec.—barely enough (even with large proportions of water) to positively carry the ash. If now the boiler row is but 200 ft. long, the channel must drop more than 6 ft. from the upstream boilers to the end of the row; and in most instances this must be added directly to the total building height.

### Early Installations

Despite these drawbacks, however, certain outstanding plants prior to 1923 did install hydraulic methods of ash handling. This was done, the author believes, in most cases with boilers equipped with underfeed stokers having a grinder ash discharge, or with chain-grate stokers where no large clinkers were anticipated. The installations were successful as designed. The simplicity of the arrangement, absence of moving parts, elimination of labor, and the fact that the ashes were not handled loose with the attendant dust, dirt, and fog, became apparent at once and offset the disadvantages which came up. Briefly, the most serious of these disadvantages were as follows:

1 The stokers discharged ashes continuously, and it was necessary to pump water continuously. This resulted in high pumping cost—from 20 to 40 kw-hr. per ton of ash moved were the usual figures.

2 The water channels or sluiceways were pitched, which resulted in the necessity of setting the stokers very high above the ash basement, and consequently in high building expense.

3 In order to minimize the pitch of the sluiceway, and therefore the building height, water velocity was kept at a minimum to safely carry the ash. As a result the ash apparently half slid, half rolled along the bottom, and wear on the sluiceway liners was extremely high.

4 The sluiceway started at one end of the boiler house and continued to the other; further, it had to run continuously. Repairs, therefore, could be made only by handling the ash discharge from all the upstream boilers by other means (usually temporary, and as such, crude).

5 It was found with the sluiceway pitches ordinarily employed that clinkers of only limited size and density could be handled. Large and dense clinker, arch tile, or the like falling into the sluice would not move; smaller material following would wedge behind and a dam would soon form, and the sluicing water would back up and overflow the channel, carrying a dirty mixture of ash and water into the basement. (This is really a corollary of (4) and (5.))

6 If the sluice dammed at the downstream end, its operation was instantly destroyed for all upstream boilers, and as they depended upon the ashes being taken away as rapidly as discharged, the cumulative results were serious.

### Designs Employed in Modern Installations

Designers in the last five years have been continuously working to retain the inherent advantages of these earlier installations and eliminate these six major disadvantages. The designs employed by many modern installations are therefore listed below.

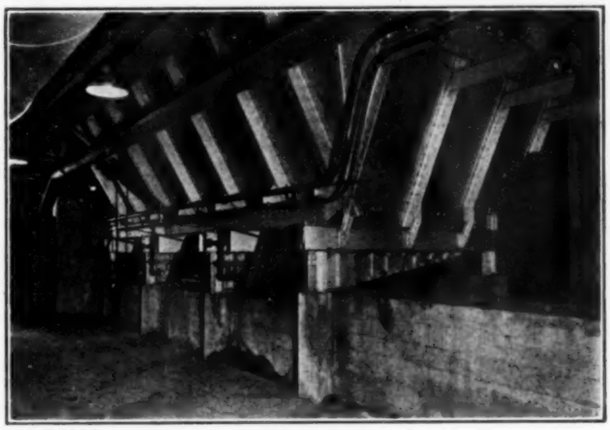

Fig. 1 Hydraulic Ash-Handling System Under a 2000-Hp. Boiler—Gould St. Plant of Consolidated Gas & Electric Co., Baltimore, Md.

(The furnace-bottom gates are opened and the ash dropped on the feed plates which are directly under the gates. The ash is then fed into a concrete sluiceway lined with nickel-cast-iron liners.)

1 To reduce the cost of pumping continuously, ash hoppers having from 8 to 20 hours ash storage between the stoker and the sluiceway are commonly employed; the instantaneous carrying capacity of the sluiceway being such that ashes accumulated in the hopper during hours can be run out in as many minutes. Many installations show water-pumping costs under these conditions of from one to two kilowatt-hours per ton of ash moved.

2 To overcome the necessity of pitching the sluiceway, water is introduced into it through nozzles at very high velocity by pumping it at high pressure (50 to 100 lb.), and then as the velocity drops along the sluiceway, introducing additional "booster" water. It was found that velocities of from 50 to 100 ft. per sec. could readily be maintained in a perfectly horizontal sluiceway for long distances (200 to 500 ft.).

3 Whereas ashes dropping into water moving at 10 to 12 ft. per sec. slide or roll along the bottom, it was found that with velocities of from 50 to 100 ft. per sec. the ash did not sink, but rather rode on top of the stream; abrasion of the sluiceway liners was thereby virtually eliminated.

4 As there was an ash storage of from 8 to 24 hours between

[1] Engineer, Allen-Sherman-Hoff Co. Assoc-Mem. A.S.M.E.

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the stokers and the sluiceway, which could be discharged in as many minutes, there remained some 23 hours per day available for repairs, should they ever be necessary.

5 As the power available in a stream of water is a direct function of the water quantity and a function of the square of the water velocity, modern plants have almost eliminated the possibility of large, dense clinker or arch tile or the like failing to move

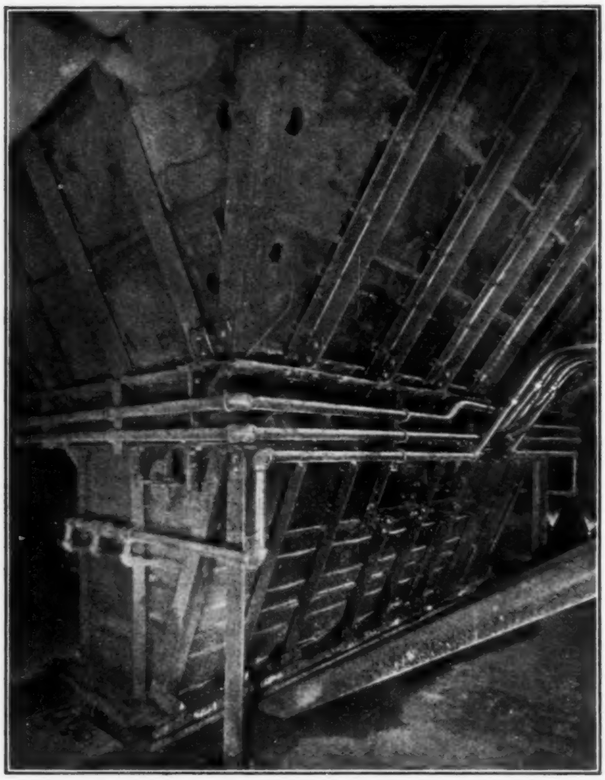

Fig. 2 Air-Cooled Furnace Bottom, Ash-Gate Section, Clinker Chamber, and Soot or Fine-Ash Collection System of Hydraulic Ash-Handling Installation in Plant of Sioux City Gas & Electric Co.

along the sluiceway. This becomes apparent when it is considered that the instantaneous quantity of water used is about the same, but its velocity in a modern plant is about in the ratio of 100 ft. per sec. to 10 ft. per sec. The instantaneous power, therefore, is about 100 times as great (the square of the velocity ratio), which means that a single clinker many times heavier can readily be moved. A modern sluiceway will readily carry a dense clinker weighing 50 to 75 lb., or to say it another way, will carry any stoker-refuse material passing 12-in. square grids.

6 Even should a modern sluice dam up (due to loss of water from the pumps or the like), operation of the plant is not seriously affected, as ashes will merely continue to accumulate in the ash hoppers until the water pressure has been reestablished and the dam broken up and discharged, when the usual method of ash discharge will be continued.

To summarize: Earlier ash sluicing was continuous and employed pitched sluiceways, which developed certain disadvantages resulting in the general adoption in modern plants having ash-storage hoppers above the sluiceway, of intermittent operation of the sluiceway, and (by use of high-pressure water producing high velocity) of horizontal sluiceways.

A most serious difficulty developed in storing ashes so that sluiceways might be intermittently operated. The original idea was that ash gates would control the flow of the ashes from the hopper to the sluice. However, it soon became apparent that it was virtually impossible by simply opening the gate which controlled an accumulation of several tons above, not to instantaneously overload the carrying capacity of the sluice below. It was therefore necessary to develop a positive means of controlling the instantaneous flow of ashes from the hopper above in proportion to the instantaneous carrying capacity of the sluice. Two general schemes have been successfully employed.

The first consisted in dropping the ashes into a mechanical feeder provided with rolls which would feed directly in proportion to the speed at which they were driven. This scheme has the double advantage of crushing any clinker which might be too large for the sluiceway to carry.

Another extremely simple and positive scheme (which has the advantage of requiring no machinery for feeding) consists in eliminating the ash gates altogether, and allowing the ashes from the stoker to drop to the slightly sloping plates forming the bottom of the ash hopper. When the hopper is full, water jets (fed from the same source of water supply as that feeding the main-sluiceway carrying nozzles) undermine the accumulated ashes, both ashes and water flowing into the sluiceway. As the undermining feedwater is from the same source as the carrying water, that is, at the same pressure, it is apparent that by proportioning the two quantities, any feeding rate may be obtained which will always be in proportion to the carrying capacity of the sluice beneath.

This scheme can only be used where no large proportion of the ash will contain clinkers individually exceeding 50 to 75 lb. in weight. Usually it is not applicable to underfeed stokers using dump-plate ash discharge. Mechanical feed (such as grinders) should be employed under this condition.

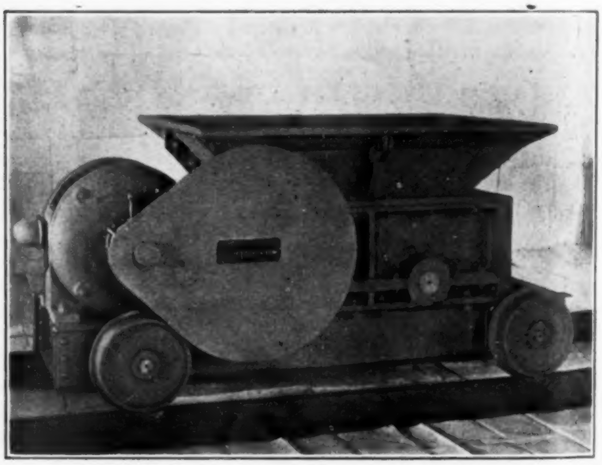

Fig. 3 Clinker Grinder on Proportioning Car Used for Feeding Ash From a Dump-Plate Stoker to a Hydraulic Ash-Handling Sluiceway

### Handling Ash From Pulverized-Fuel Furnaces

Modern hydraulic ash handling is particularly applicable to ash from pulverized-fuel furnaces. It has been found that on the average about 25 per cent of the total ash in the fuel where powdered coal is employed is collected in the ashpit proper. Another 15 to 20 per cent is collected from the second pass of the boiler, from hoppers beneath economizers or air heaters, from flues, and from the base of the stacks. A horizontal sluiceway may thus readily be used to collect dust from many sources through comparatively small pipes run almost at will. By carrying this dust mixed with water and virtually as a fluid, none of the

problems of flow angles along various substances enter—all of which results in amazing simplicity of design.

Of particular importance, where pulverized coal is burned, is the fact that in a modern hydraulic ash-handling system the ashes and dust are not handled loose; the system is totally enclosed and the refuse ends its trip under water. The impracticability

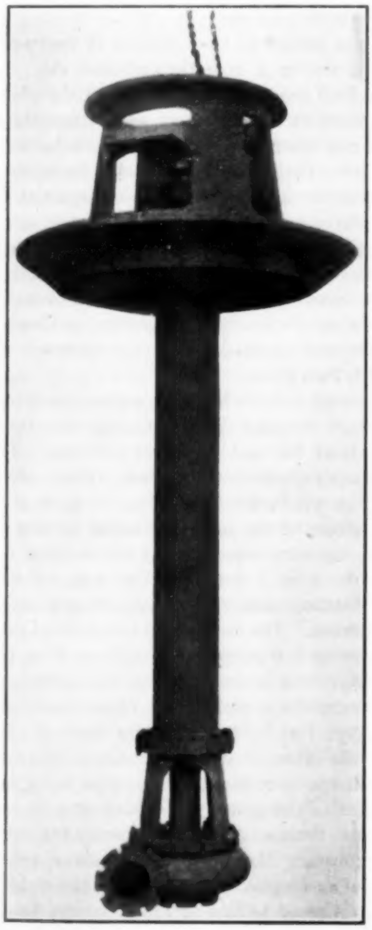

Fig. 4 Vertical Manganese-Steel Pump Used for Discharging Ashes Either to Fill or to Tanks

of handling such ashes by dropping them dry and loose into cars or an open conveying system can readily be seen when it is appreciated that a great proportion of the ashes in such a coal-burning system are as impalpable as talcum powder or cement dust. Handled loose they float in suspension in the air, permeating the entire power house, with probable serious effects on moving machinery.

In handling ashes beneath pulverized-fuel furnaces attention is particularly called to the necessity of having an ash storage space well protected from the direct heat of the furnace; otherwise the ash may fuse and serious trouble result. It is always necessary to have an ash gate between the ash-storage hopper and the sluiceway where pulverized fuel is used, to prevent excess air entering the furnace.

The Buffalo General Electric Company have been successful in handling ash as molten slag by means of hydraulic ash handling. The furnace is of the well type, and ash melts and accumulates as a molten pool at the bottom of the well. This is tapped off daily, dropping to high-velocity water jets which instantaneously chill and disintegrate it. The chilled particles are carried by an ordinary high-velocity horizontal sluiceway to a sump, from which point they are pumped by manganese-steel centrifugal pumps to a fill some 1100 ft. distant.

### Ash Disposal

It is now necessary to consider the final disposition of the ashes after they have been hydraulically accumulated into a central sump. There are several well-developed means, as follows:

1 The ashes and water, where elevations and distances permit, may be sluiced direct to the fill, the ashes remaining and the water leaching back into the ground or flowing to creek or river.

2 The ashes and water, where elevations or distances or both do not permit sluicing direct to the fill, may be sluiced to a central sump and pumped by manganese-steel pumps to the fill, the ashes remaining and the water being disposed of as before. This scheme requires a very small sump, as ashes and water are taken out as fast as they come in.

3 The same as (2) except the ashes and water are pumped into an overhead bin, the water flowing out (through water-collecting ash gates at the bottom of the bin) to the sewer, and the ashes remaining to be dumped later into railroad cars, auto trucks, or the like for final disposition. As in case (2), a very small sump is required.

4 The ashes and water may be sluiced to a large sump, the ashes stored therein, and the water allowed to overflow to the sewer. Of course, combinations of any of these schemes may be employed, but the four cases outlined are fundamental.

Where water is a valuable commodity it may be recirculated after dropping out the ashes. In such a case not more than 1 lb. of water per 10 lb. of ash moved is required as make-up.

In closing, it is interesting to note that the material handling section of the Prime Movers Committee of the N.E.L.A. said in their 1926–27 report that of 38 plants examined that were built prior to 1924, about 15 per cent used hydraulic means of ash handling, whereas of 24 plants investigated that were built since that time, 50 per cent employed this means. The cost analysis showed that of all the ash-handling means employed in all the plants examined, the hydraulic showed 30 per cent less cost per ton of ashes handled than the next best means.

## Discussion

Charles H. Bigelow.[2] About 30 years ago, while I was with the West End Street Railway Company in Boston, we designed a power plant at Charlestown and there we installed sluiceways under all the boilers through which we discharged the water from the condensers. They were hand-fired grates; the ashes fell into the sluices and were carried out, and that part of it worked successfully. The water discharged upon the flats; there was a bulkhead quite a way out, and we thought we could fill up the flats without trouble, but unfortunately the water carried the ashes too far out into the channel. The Harbor Commission got after us, and we had to stop it. We had an unlimited supply of water while we were running, all our discharge water from the condensers flowing along these channels, and it worked very well as far as it went.

### Author's Closure

As to Mr. Bigelow's comments, I understand that there have been various plants in the country that have used condenser water and in some cases waste water from stills, etc., the water being led in a stream under the boilers, from which the ashes are dropped, and carried to a fill. Mr. Bigelow brought out the fact that the ash carried quite a distance out into the channel.

[2] Plant Engineer, Spicer Mfg. Corp., South Plainfield, N. J. Mem. A.S.M.E.

That is a peculiar feature of hydraulic ash disposal. When we think of it, ash travels just as sand does.

I visited the Ford Motor plant in St. Paul about two years ago, a year and a half after we had installed a complete hydraulic ash-handling system. The ash is moved from two boilers and two gas generators to a small sump, from which it is pumped to a fill. I expected to find the ash in a large pile at the discharge end of the pipe line, but instead it had drifted to various places and at that time had built up 8 or 10 in. around the trees for an area of approximately half an acre.

Harry S. Ford[3] asks whether the 14 cents per ton of ash handled at Media, which I mentioned in my oral presentation of the paper, includes the total cost. I might say that it does not, and that he also misunderstood me. It is 14 cents a day for the cost of pumping the water, and that is the only cost other than the original installation cost of the particular job. There has been absolutely no maintenance at that particular plant, and it has been in operation over a year and a half. The ash is sluiced 500 ft. to fill in 7 minutes or less per day.

As to the maintenance charge of which Mr. Ford speaks, the job at the Ford Motor Company has been in use for about three years, and to my knowledge we never shipped them any spare parts or equipment for making repairs to their installation. They use pumps and discharge the ashes alongside the Mississippi River bank.

Mr. Ford also brings up the matter of abrasion. As I stated, the abrasion is virtually eliminated. Here in Philadelphia we have a plant in which 50 tons of ashes a day are handled. Originally, we installed in the sluice at this plant 160 ft. of quarter-round liners. These were designed with the idea that after the bottoms of the liners wore they could be reversed and the side be used then at the bottom. There was also about 185 ft. of half-round liners. However, owing to the velocity of the water and the effectiveness in moving the material, it would also move the quarter-round liners to the sump after the bottom of the liner had worn enough to allow the water to get beneath them. Now, at the time those liners were installed, ordinary cast iron $^5/_8$ in. thick was used. However, the full half-round liners that were also installed in the plant have been in use with about 50 tons of ashes a day passing over them, and they have been renewed this year. These are the liners that are in the mouth of the sluice itself, at the discharge end—say, the last 50 or 60 ft. of the sluice. This means that it took almost three years to wear down half-round liners only $^5/_8$ in. thick. At present we are supplying nickel liners $1^1/_8$ in. thick in place of the ordinary cast-iron liners.

Mr. Ford also makes mention of the shut-off gate under the hopper. He states that in case such wear took place, there would be about 23 hours a day for repairs because the gates could be kept closed, and desires to know what would happen when no gates were installed. Mr. Ford is evidently referring to a powdered-fuel furnace. In this case, feed plates are set at an angle of approximately 15 deg. and are located beneath the ash gates. These gates seal off the bottom of the furnace. Without gates, another type of seal would be necessary to give the proper control of furnace gases. Consequently, we obtain time for the removal of old liners and the installation of new liners in relation to the carrying capacity of the hopper itself. It is very easy to install these liners as 30 ft. of liners can be installed by means of turnbuckles in $2^1/_2$ hours.

Mr. Ford also brings up the question of feed nozzles, not undermining but boring a hole through the ash. Originally we attempted to feed the ash from the top of the plate downward. This did not meet with real success, as at times the whole charge of ash would run down in an avalanche, similar to dropping the ash directly from the gates themselves. An improvement over that design was the installation of two nozzles at the lower end of the feed plate, one at each side, with the streams crossing each other at the upper end of the feed plate; this water undermined the ash from the lower end of the feed plate, and positive control of the quantity of the ash fed was obtained.

Since that time we have developed an oscillating nozzle and use only one hand-operated or power-operated nozzle at the bottom of each feed plate.

The next question is on how the water was drained from the tank. Mr. Ford is quite right in saying that the discharge to the tank is about 600 gal. of water per min. The statement made in the paper should be amplified. There are two methods of doing it, the preferable one being to have a weir running around the bottom of the tank, the water flowing over the weir and then running to waste, or being recirculated in the system. However, in the tank I described this was not the case. The tank was an existing tank and the aforementioned arrangement was not adaptable. The water was taken from its top level by means of lowering a 6-in. pipe through an 8-in. pipe. On top of the 6-in. pipe was a cross-fitting, and attached to the top flange of the cross-tee a piston rod, which maintained the cross on the 6-in. pipe just below the water level of the tank. The two inlets of the cross allowed the water to enter the 6-in. pipe and then discharge to waste, the 6-in. pipe being lowered to the ashes by means of the piston rod which was operated with hydraulic pressure, through a manually controlled valve.

The next question Mr. Ford asks is about recirculating the water. This is accomplished by allowing the water to pass over and under a series of baffles at low velocity, to allow the ash particles to drop out, and then repumping the clear water resulting back to the sluice nozzles. We require about 1 lb. of water in actual "make-up" for each 10 lb. of ash handled, based upon the average operation where the ashes are quenched prior to sluicing. The circulating arrangement has been in use in Harrisburg more than 10 years, and as to the effect on the pumps, I cannot definitely state. I might say that the new Kips Bay Station in New York is going in on the same basis.

The last question Mr. Ford asks is again about maintenance and how to compare costs. I personally have not compared these costs. I have used the report of the Prime Movers Committee. As to how they base their analysis, I am not certain.

[3] Eastern Sales Manager, R. H. Beaumont Co., Philadelphia, Pa. Assoc-Mem. A.S.M.E.

# Modern Handling Methods of Railroad Transportation

## Meeting Freight-Traffic Problems at the Terminal Discussed—Use of Unit Containers in Transporting Merchandise in L.C.L. and Full-Carload Lots

By G. C. WOODRUFF,[1] NEW YORK, N. Y.

OVER the great golden dome of the Transportation Building of the World's Fair of 1893 there was the caption: "The easy progress of men and things from place to place makes a nation strong and great." This to a very great degree at that time typified, and during the succeeding years has continued to typify, the advance of America through the current and never-ending improvements in transportation.

Other nations may have elements which would seem to make for prosperity and advancement, such as education, fertile acres, and extensive territory, but a comparison of the progress of such nations with the progress of these United States in the past fifty years would show without question that because of its transportation the United States has advanced in a degree far exceeding the advance of other nations of the world.

The term "transportation," however, has perhaps been used in too narrow a sense in that it has essentially been confined to the movement between distinct places rather than to all elements included in transportation, such as for instance the movement within a restricted area or a given terminal, which embraces all methods for the better and more economical handling of the goods which are to be or have been transported. Therefore any undertaking which would benefit those most vitally interested in terminal handling, namely, the shipping and receiving public and the railroads, would be properly considered as an important advance in transportation.

The request to prepare a paper on this subject mentioned certain phases which it was desired should be discussed, and as only passing mention may be made of many of the activities, the features of largest importance and greatest interest to mechanical engineers will be stressed.

The handling of unit containers will first be discussed, and in that discussion there will necessarily be brought in some of the other elements, such as overhead cranes, electric lift trucks, and motor trucks, for it will be shown that each and all serve an important part in the ultimate development of this one phase of terminal handling.

The handling of unit containers may be subdivided into two parts, the handling of merchandise freight or what is commonly known as less-than-carload-lot traffic, and the handling of rough or bulk freight in carload traffic.

### Handling Merchandise Freight

For the past fifty years or more the methods in handling merchandise freight have not been changed to any marked degree, in that packages of various kinds, shapes, and sizes have been tendered at the railroad platform, taken by railroad labor after unloading from the shipper's truck, and either directly loaded into a car or more frequently placed upon the freight-house floor until the car could be loaded, and then trucked to the car for relatively long distances and stowed in the car. Owing to the usual limitations in available extra space, particularly at larger terminals, in many instances the freight must be loaded into the car currently as offered, which often has resulted in an ill-assorted and badly loaded car, because it was not possible to reassort and properly load the freight to the best advantage.

Obviously if heavy packages were offered late in the day and the car was two-thirds loaded, it would not be practical to unload the car and reload it on account of the cost and lack of time, so that in actual practice another car would be loaded, resulting in relatively light loads for both cars.

The freight having been loaded in the car, the car would be transported sometimes to destination and sometimes to a transfer, where the freight would be taken out and there reloaded in another car, in the case of a transfer, or unloaded from the car at the destination point, placed in the freight house, and later on picked up again and taken to the doorway for delivery to the consignee's truck. In the case of the transferred freight an intermediate unloading and rehandling would also be necessary.

A study of the cost of handling L.C.L. merchandise freight made during the Railroad Administration developed that for 88 representative cities in the Eastern section, the amounts which must be charged against the handling of L.C.L. merchandise would be on the average 10.4 cents per 100 lb. at each end of the route. Obviously a railroad having the point of origin and the terminal both on its rails would be saddled with the extra expense of 20.8 cents per 100 lb. for mere terminal handling.

In addition it was pointed out by Attorney Examiner Flynn in Docket 18000 in the matter of motor-coach and motor-truck operation, incident to general discussion of L.C.L. tonnage, that "although the less-than-carload tonnage in 1924 constituted $3^1/_3$ per cent of the total tonnage handled by Class 1 steam railroads, it is stated that 25.7 per cent of the railroads' equipment was used to handle it and 32.2 per cent of claims paid were on this less-than-carload traffic." It will be observed, however, that the relationship of tonnage, cars used, and claims paid on this L.C.L. merchandise is altogether out of proportion.

In addition the loading of merchandise cars to specified points owing to the necessity of handling, as outlined in the first part of this paper, has necessarily resulted in very lightly loaded cars and a duplication of service without consequent proper relative revenue. Further, the investment in terminal facilities, including warehouses, tracks, and other operating facilities, is much out of proportion to the tonnage and revenue resulting, and in addition the railroads as a whole are consistently faced with demands for increased capital expenditures for facilities to take care of the L.C.L. merchandise business. In many of the larger cities such facilities can be obtained only at almost prohibitive prices, if at all.

Such a situation has naturally been a matter for deep thought by those responsible for the proper operation and monetary returns by the railroad. It would have been an easy matter to have corrected this situation to a considerable degree by holding freight over or doubling it up, but in such a procedure the interest of that factor most vitally concerned would not have been properly taken care of, namely, the public, and in the final analysis as a public servant the railroad owes its first duty to that public and

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must give reasonable service, bearing in mind the commercial necessities of this particular traffic.

Since the War, with the rehabilitation of the railroads generally it is perhaps fair to say that the brand of service offered has never been better, and the public has been led, and properly so, to expect continuous daily reliable service, so that they have been in a position to cut down inventories and depend on regular receipts for their daily needs.

There have been many things thought of, and among them—and perhaps presenting, at least to as large a degree as any, favorable comment—is the unit container as typified by the L.C.L. merchandise container, which, following a number of years of development starting back of 1922, first was in operation in 1922 in a very limited way, and by constant experimentation and endeavoring to change for the better has been gradually improved and extended until it is being increasingly used in handling L.C.L. merchandise traffic between important centers.

Picture a large box or a container having a capacity of 438 cu. ft., with outside dimensions of width 7 ft. $2\frac{1}{2}$ in., height 8 ft. $2\frac{1}{2}$ in., length over guides 9 ft. $3\frac{1}{2}$ in., and with inside dimensions of width 7 ft., height at eaves 7 ft. 1 in., length 8 ft., 10 in., provided with eyes at the four corners, with straps by which an overhead crane or other conveyor can lift it from the truck to the car or from the car to the truck, and fitted into place on the car by means of guides and slots so each is firmly held and all possibility of side sway or other change of location is avoided.

Such containers are handled on a car about 47 ft. long by 9 ft. $3\frac{1}{2}$ in. wide, of low-side gondola type, equipped with guides into which the containers fit. The containers have a tight door and are leak-proof in every particular. The doors are locked and the method of carrying the containers on the car makes it impossible to open them in transit. This is important in that it absolutely does away with opportunity for pilfering while in the railroad possession, and as it is locked by the shippers and unlocked by the consignees with their own locks and keys, the possibility of their being opened by any one on the truck at either end of the route is practically nil.

In addition, as six of these containers are used on the present type of car, the liability of damage claims is reduced to almost nothing in that the goods to be transported are divided into six units, which in effect are protected against each other by double bulkheads. The advantages of this method of transportation are of value both to the transportation agency, which is the railroad, and to the public, which is the shippers and the consignees. Each container can handle a maximum load of 8500 lb. of miscellaneous freight, and the rate structure, as developed, makes it advantageous to the shipper or receiver to have the containers loaded as nearly full as possible, with the results that if each container should be loaded full there would be a car of 51,000 lb. of mixed merchandise as compared with the ordinary loading of merchandise freight in box cars of about 15,000 lb.

The goods are loaded in a container by a shipper and are unloaded from the containers by the consignee so that in comparison with ordinary merchandise freight that is loaded into the cars by a carrier and similarly unloaded from the cars by a carrier, the saving in labor alone is important.

In addition, if in ordinary transportation the carriers had the equivalent of the amount of freight shown as capable of being transported in one unit of six containers per car, they would in their ordinary method of handling have to use at least two to three merchandise cars to transport such aggregate freight, which would mean in addition to the capital investment in one or two extra cars the actual road-run cost of the operation of these cars as against the one car, not to mention the extra switching at each end of the line and the house space taken up by the extra cars. Further economies are possible to the railroad in that the billing is by container rather than by item, and it seems needless to point out that with an average expense per billing item of about 15 cents the saving of hundreds of billing items would mean a radical economy from the accounting department standpoint.

From the standpoint of the user of the containers, the shipper or the consignee, the advantages and economies are equally important, because a basis of rates has been developed which departs from the usual official classification basis and is on the mileage and bulk loading of miscellaneous articles in the container, all articles proper to be transported in the container being charged at the same rate, which is a certain figure per mile for a certain fixed minimum amount of tonnage in the container. These charges are increased as the weight increases to the maximum, but the resultant rate if reduced back into cents per 100 lb. is relatively less per 100 lb. as the containers are loaded to or nearly to their maximum. In addition the charges are on the weight of the contents of the container, and it is not necessary in container shipments to pack the goods in the same manner as prescribed by the official classification or in ordinary railroad shipping, and therefore light packages or simply paper wrappings can be used, with a considerable saving in that part as well.

The lack of pilferage is equally important to the shipper or consignee, and the almost total cessation of damages presents an attraction in the service. Further, from a handling standpoint, the containers are loaded at the shipper's place of business, trucked to the railroad, either by the shipper or under contract with outside truckman, the railroad having no part in this undertaking, put as a lot on the car, and at destination trucked to consignee's place of business. Here they can be unloaded on the truck or can be taken off the truck and put on the consignee's platform for handling at his convenience.

It is becoming generally recognized that the use of unit containers is of increasing importance, and the development of the L.C.L. merchandise container has appealed to the railroads as it is being used in larger numbers each year. The point of view of the railroads is expressed in the following quotation from an address at Dallas, Texas, on October 18, 1927, by the chief executive of one of the principal railroads of the country:

"We are doing new things. For instance, the railroads are developing new plans of packing in containers which can be lifted from a motor truck in one city one evening, placed in a car and moved overnight, and early the next morning taken off the railroad car and put on another motor truck and delivered to destination promptly. This development of container transportation promises to revolutionize many of our methods. It may ultimately relieve us of one of the most expensive of our activities in the handling of less-than-carload freight at transfer stations."

The use of the L.C.L. merchandise container becomes increasingly possible at the smaller stations as ways and means are developed for best handling it, and it is felt that ultimately it will to a large degree solve the question of the expensive wayfreight handling to and from such small stations, and in addition present a means by which service to and from such small stations from and to the large cities of the country may be put on a parity with service from the larger ones where straight cars now are run.

As an illustration, on a railroad A, for instance, six relatively small towns, important commercially, have a limited volume of freight for six large receiving centers in the West, but no one town has enough, daily or semi-weekly or tri-weekly, to load a straight car to such destinations.

Under the box-car method of handling, such freight must load in a car to a transfer and then either load to another transfer or into a straight car. In any event there is delay and additional expense, with possibilities of claims for loss and damage, etc.

In the container method it is entirely feasible to have each of

these small towns either daily or on a certain number of days per week load a container car with six containers, each of the six containers for a different destination, but the destinations to be the same in the six cars, and then stop the cars at the first proper point and reassort the containers so that when the cars leave this first point there will be six containers in each car, but each car will have its six containers loaded for the same point. In other words, there will be a straight car for each of six points, and the cost of such rehandling is very small in comparison with the cost of ordinary transfer handling. Further, the load per car would be very much in excess of any load possible from the transfer, so that it may fairly be said that all expense incident to the container method is more than absorbed by the economies made possible.

### Containers for Bulk Freight

The containers for handling bulk freight, such as brick, limestone, sand, and other bulk materials, present a somewhat different situation in that the handling costs involved in the ordinary transportation methods as against the handling costs involved in the container method must serve as a basis of comparison. The brick containers have dimensions approximately half those of the merchandise containers, and they have inside dimensions of width 4 ft. 1 in., height 7 ft. $4^3/_4$ in., length 6 ft. $11^3/_4$ in. and outside dimensions of width over guides 4 ft. $8^3/_4$ in., height over lifting brackets 8 ft. 4 in., approximately, length 7 ft. $2^1/_2$ in., and a capacity of 210 cu. ft., and an average light weight of 2,300 lb.

They were designed purposely of these dimensions to accommodate 3000 ordinary Hudson River brick thrown in at random, as this number represented the ordinary truckload of brick. The containers are of substantial construction, with special devices for opening the bottom doors by dropping them and for closing them after the brick had come out, a rain- or snow-deflecting top, and with lifting eyes on the four corners. In addition, through special devices the containers can be opened or closed while suspended from the crane. It may be mentioned that this particular size is not in any way necessary as the size can be varied to suit particular conditions, but so far it has been shown to meet a variety of uses as will be outlined later.

For many years the method of handling brick has been in water-borne barges, or in box cars, stacked, or in open tops, thrown in. The first method is possible only in the season of navigation and presents great expense in handling at the point of making the brick, because so many human handlings are involved, and there are similar expenses in unloading from the barge to the truck. The second method presents similar expense in human handling at both ends of the line, and the third perhaps more so owing to the hardship in unloading a gondola car by human hands. In addition the breakage was large and the truck cost out of all proportion owing to the waiting time while the trucks were being loaded.

Therefore a container which would allow the mechanical placement of the brick from the kiln into such a container on a count basis of 3000 brick, their transportation mechanically to the car if the container is not being loaded while on the car, and their transportation in large volume to the point of destination to be unloaded in about one-tenth of the time necessary for a similar number of brick from the barge or the car, appeared to present an opportunity not to be lightly disregarded.

After much experimentation the L.C.L. bulk container was developed to hold 3000 brick each, with 12 units or 36,000 brick per car, which is a load of approximately 132,000 lb. per car. This is about double the largest car handled by the railroad, and it is possible to unload the whole car in actual practice in less than an hour as against at least two days by hand unloading for half the quantity or four days for a similar quantity. The rates charged for transporting are substantially those charged for rail transportation on a similar basis.

Data developed by the Brick Association independently of the railroad showed that there was a motor-truck efficiency in the handling at destination of at least two to one on a 3000-brick basis, and as trucks have been developed for handling 6000 brick the motor-truck efficiency will be nearer four to one, which means that on a basis of a truck costing $30 per day and with container-car brick the truck could handle four times as many brick in a given length of time or do the work of four trucks.

Incidentally while mention is made of unloading a brick container in less than five minutes in actual performance at a given installation where there are two gantry cranes and spanning tracks holding 23 container cars, 293 containers have been unloaded in one day of eight working hours, or 18 containers for each crane per hour, an average of less than $3^1/_2$ min. per container. The speed was limited only by the ability of the trucks to get into position and into and out of the yard.

On a large volume of this traffic this means double the load and at least double the efficiency in unloading time, or an efficiency of at least four to one for the brick container as against the ordinary box car, but it further means that if such tonnage were transported in box cars there would be necessary four times the amount of track room for handling a given volume of tonnage; and as obviously at any center capable of receiving such traffic it would be impossible to produce at any cost four times the available track room, it may fairly be said that new terminals are created without any material increase of capital expenditure for such terminals other than the cost of the cranes and of their operation.

These of course are furnished in common practice for handling heavy freight, but even charging such cost of operation and such cost of installation against the undertaking on a basis of two-thirds daily use, the figures represent for all items of cost, installation, operation, maintenance, and amortization on a 10-year basis, about 23 cents per container.

Bear in mind also that to the railroad the ability to handle such large loads in one car instead of two cars represents a considerable economy both as to road-haul costs and terminal-switching costs at both ends, together with capital investment, economies as to cars, and maintenance on the cars, all of which would more than overcome any direct expense properly to be attributed to the container method of handling.

The bulk container as applied to brick has been discussed in detail, but in actual practice it is also being applied to bulk lime, a leakproof bottom and a leakproof top being supplied. Whereas the bulk lime had formerly been transported in box cars on a basis of 40,000 lb. to a car, it is now being transported in containers on container cars on the basis of 130,000 lb. pei car at the same rates as charged per ton in the box car, or better than three to one in favor of the container car.

From the standpoint of the consignee there is a saving of at least 50 cents a ton in unloading costs and in trucking costs as well, and from the standpoint of the railroad there is a high revenue per car realized, together with the economies incident to the brick traffic already described.

Refuse quarry stone is also being regularly transported in large quantities from a rail quarry to the lakes, the containers being taken out on barges and dumped into the crib for making a breakwater. The success of this is so marked that the operations will be largely extended during the coming season. There are other types of containers for handling bulk sand, gravel, and in fact any rough articles, also for handling building tile, cement, hollow tile, interior finish, fireproofing, sewer pipe, etc., of which time and space will not permit detailed discussion.

The container has been emphasized because such special em-

phasis seemed desirable. In the use of the containers overhead cranes have played a large part, but the use of overhead cranes is not limited to the container in any way, for in the experience of the particular railroad with which the author is connected they have been developed for handling in a large way boxed automobiles at water terminals in New York (Weehawken) for gradually replacing the pillar or fixed crane. It is interesting to note that experience has shown that a relatively light-capacity crane will take care of a very large percentage of freight for which cranes must be used, and that in the few cases where very heavy pieces must be handled it is usually better practice to call out a locomotive crane for short usage rather than tie up an investment in a high-capacity crane where it is not used except to a limited degree. This leads to the belief that 10-ton cranes and 20-ton cranes will perhaps, with some few exceptions, become standard for this use.

The electric lift truck is also used with the container, but is also an increasingly important development apart from it. As applied to the container the lift truck can pick up the container, take it from a truck into a warehouse, place it where desired, pick it up again and put it back on the truck, and either put it on the car or do so with the help of the crane. The future will prove the degree to which the two methods are best suited. My opinion leans to a preference for the crane lifting where a large number of units to be handled in the shortest possible time are involved, and for the lift truck where there are a few units and more time is available, but the two together present the perfected method of handling. Lift trucks are also used in shop work, in handling materials, in the stores department for similar work, in our baggage service, and in many minor useful operations.

### Motor Trucks

The use of motor trucks might well deserve a paper by itself and can be outlined only very briefly. It has early been recognized that the motor truck in its development and possibilities presented the aspect not of a competitor but rather of something to be used by the railroad in its activities, and the difficulty has been to determine just wherein that use properly lay. There has been much talk and much written concerning motor-truck competition, but in a true sense this has been, I think, a most unfortunate phrase, for rather the motor truck should be considered an ally of the railroads; and those developing the motor truck should be as truly anxious as those working for the best interests of the railroads to come to some mutual understanding as to the proper functions and uses of the two agencies.

It may be said that each side has gone too far, and to a degree that is true, but as the years of usage develop experience and perhaps saner judgment. I think it will be readily agreed that the motor truck should not be used in long hauls over the road except in special cases, as this field lies properly within the sphere of railroad activity. On the other hand, for the relatively short hauls, for terminal work, for interchange involving hauls of not in excess of 35 miles, the motor truck should, and I think will, come into its proper sphere.

Speaking with a somewhat intimate knowledge of the endeavors of one railroad in the use of motor trucks, I may say that it has increasingly made use of this agency during the past five years or more and that its use is an extension of what was formerly done by horse-drawn trucks, starting with consolidation, as between freight stations in the larger centers, extending to certain trucking in place of handling by water, then to trucking between stations and eliminating way-freight service or other train service, trucking for interchange between railroads at various terminals, trucking across country between parallel lines of the same railroads situated 8 or 10 miles apart, rather than hauling by rail around long distances to get to the other division, and in some cases in place of trap and ferry-car service, etc.

The railroad, however, has not endeavored in any way to do more than use the trucking agency which presented itself on the basis of contracts with outside truckmen, and has not undertaken to operate trucks itself. By so doing it has perhaps stimulated public good-will in the towns where such operations have been perfected rather than having incurred any public ill-will, and in addition it has made use of going organizations and has endeavored to have a type of equipment used which would result in the lowest proper rates to be charged for the service rendered. In certain phases tractor and trailer equipment seems to be the best, in others straight trucks, and in still others a combination of the two, but it is not felt that it is competent to pass upon these features or the features of the mechanical part other than as it affects the service or the rates which it pays for such service.

Motor trucking as used by the railroad started from nothing and developed in various phases without very many preconceived plans, and the effort of the railroad has been, as it assumed relatively large proportions in its trucking activities, to work to some common ground of understanding and to some general basis wherein trucking activities would be found to be justified or unjustified as compared with rail operation, and in doing this it has had to establish the factors favorable and unfavorable to trucking operation in a given sphere of activity. Its studies have so far progressed as to set down in a formula such factors, weighing one against the other and then coming to a decision, so that each trucking activity conforms to a general plan while perhaps presenting special features of its own.

The efforts in trucking have been improved service, recognizing the obligation to the public, actual monetary economics where practical, better use of facilities, and the elimination of duplicate service, which makes for economy. Where all these factors and many minor ones could be combined the result is plain, but there are many trucking activities in which the results, while intangible and difficult to set down in black and white, are nevertheless important, all of which must be considered.

Many of the other railroads are pursuing similar activities in trucking, and the experience of the large trucking manufacturers has been of great assistance in avoiding serious errors to as great a degree as is practicable. The future in trucking can best be judged by the past. It is becoming stabilized and will be, in my opinion, largely increased in practical use by the railroads as a whole.

There are many other activities with the railroads in the handling at terminals and along the way which contribute to the general success of railroad operation and the satisfaction of service by the public, but I have endeavored to cover only some of the activities which it seems to us do contribute to improvement in service, in methods, and where possible the lowering of costs to the public, together with better returns for the real owners of the railroads.

## Discussion

F. J. Shepard, Jr.[2] Our experience during several years shows large savings of time and money by handling materials in larger units through labor-saving machines in connection with present railroad equipment.

In 1926 we built for a paper manufacturer 1200 paper-clamping platforms of a returnable type. These are used in shipping coated stock from the mills at Lawrence, Mass., to the printer at Washington. Each platform handles a 4600-lb. load of 40 × 60-in. sheets, the equivalent of four cases as formerly packed. Lift

[2] Chief Engineer, Lewis-Shepard Co., Boston, Mass. Assoc-Mem. A.S.M.E.

trucks place 12 to 14 platform loads in each box car, and they are removed in the same manner at destination. The empty platforms are returned to the mill in carload lots at a low freight cost.

Briefly, the following results have been obtained: A saving of four packing cases at \$2.50 per case for each platform load of paper; loading time cut to one-sixth as 12 platforms are placed in the car in $1^1/_2$ hours with hand-lift trucks; unloading time decreased from 22 man-hours to 6 man-hours; the unpacking of cases eliminated as the paper is used directly from the platforms after removing the clamping tops; spoilage materially reduced, as when the paper was in cases, the five or six lower sheets were badly creased and could not be used.

It is estimated that the \$30,000 worth of platforms paid for themselves in the first nine months. The use of returnable platforms is advantageous where a mill is serving a large user with a standard-size sheet. A cheaper, non-returnable type is used in shipping to smaller users and jobbers, with a like saving in cost over boxing.

In the handling of L.C.L. freight at the new Monon freight house at Indianapolis the use of hand-lift trucks and platforms cut the handling cost from 73 cents per ton to 48 cents. Approximately 250 tons per day is handled through this house on 500 platforms and 16 hand-lift trucks.

Another advantage was in the orderliness of the freight house and the ease of dispatching goods to different cars. Incoming goods for various destinations are placed on separate platforms and are moved into the cars in loads of from 1500 to 3000 lb. Shipments received as late as 4 o'clock in the afternoon are on their way by 5:30 p.m.

The use of materials-handling machines in loading the present railroad equipment to capacity is also resulting in large savings.

An automobile-body manufacturer in the East in shipping to Detroit was loading five bodies on a box-car floor. By using portable elevators in connection with a special lifting dolly and special decking frames the number of bodies per car was increased to 10, which halved the freight per body to destination. The saving amounted to about \$4000 a day after allowing for extra labor and the cost of the special equipment used in double-decking the bodies and return freight on decking frames.

Charles H. Bigelow.[3] In handling the accessories for automobiles we have gone into this matter of containers extensively. In one plant in shipping forgings we first tried loading them in the car, then later we used containers that could be handled by a lift truck. These containers could be built up in tiers by putting on extensions and bolting them down. We are now shipping the materials in these containers by loading them into the car with lift trucks, and then they are taken out at the other end and emptied, and the containers are brought back. In other cases we are shipping the parts packed in the car without containers or boxing, by crating right in the car. They are unloaded at the automobile factories and practically go right on to the conveying line. This handling with containers has made a big saving. We have tried different plans of making up crates for these accessories, but some of the crates are not so successful. The corrugated-iron box has worked out very well as a conveyor.

In connection with lift trucks we use both electric and gasoline trucks. The electric lift trucks have advantages on a smooth floor, but if they get into snow in the yard there will be trouble. Gasoline lift trucks are now on the market that will work better on a rough surface and will do harder work and stand more abuse.

[3] Plant Engineer, Spicer Mfg. Co., South Plainfield, N. J. Mem. A.S.M.E.

George E. Hagemann.[4] A question came up about the cost of electric-truck operation and the chance for the public utility to sell power for charging the batteries to businesses using electric trucks. At the 1927 A.S.M.E. annual meeting in New York a paper[5] was presented giving in considerable detail the costs of operating electric trucks. This paper was by C. B. Crockett and H. J. Payne, who are connected with the Society for Electrical Development, Inc., an association which has contact with practically all electric manufacturers in the country, and consequently has access to reliable data.

The question of freight handling is not altogether a railroad proposition, but is taking on more distinctly a manufacturing aspect. In the old days the railroad was considered as an unfriendly outside organization, one which occasionally smashed things, delayed merchandise, and sent shipments to the wrong places. This has all been changed. The railroads are giving efficient service. They have cooperatively worked with manufacturers to the extent that now the railroad is, in effect, an adjunct of the manufacturing plant, a huge storeroom of incoming supplies that spreads all over the country and happens to be on wheels. As such, it fits into the comprehensive industrial plan of reducing handling costs.

After all, when we talk about materials handling we should consider that as much of the handling part as possible should be lopped off. The whole object of the A.S.M.E. Materials Handling Division is not to develop ways and means of more handling, but of less handling; that is, when something gets on the move, keep it on the move, and do not handle it any more than is positively necessary. "Handling," from its derivation, implies handwork somewhere down the line, and we want to get away from that as much as possible.

We can profitably study what many outstanding manufacturing companies of this country are doing today to reduce manual labor in their plants and get rid of most of the transfer-and-stop procedure between processing operations. Instead of taking a part or material up at one place, moving it a few feet, and setting it down, then somebody else picking it up, doing something on it, moving it a few feet, and so on, and having, say, a hundred men on the payroll engaged in nothing but moving material around, plants have transferred these men to productive work and have installed equipment which will move the product automatically. Not only that, but often the equipment is of a type which permits the man to work on the material or part while it is moving. In some cases the man moves along with the work, such as for instance on foundry conveyors, where he steps on the conveyor and pours castings while the conveyor is on the move.

These developments in keeping materials in motion have gone beyond the industrial plant and now extend to the shipping field. The railroad is today considered by many large corporations really as part of their storeroom facilities. A company ordering materials may place a commitment to cover a long period, but will specify when and how the shipments are to be made. In order not to have large shipments coming in all at one time, they may route the materials over as many as three or four different lines, to space their arrival over one or more days' intervals. I believe the freight rate is about the same. The intervals of a day or more between the time of arrival of shipments at the plant are planned so that the bulk of the materials may be taken directly to the point of use in the factory. The Goodyear Tire and Rubber Company, the Nordyke-Marmon Company, the Ford Motor Company, and many other plants formerly carried large

[4] Managing Editor, *Manufacturing Industries*, New York, N. Y. Mem. A.S.M.E.

[5] See "Operating Costs of Electric Industrial Trucks and Tractors," C. B. Crockett and H. J. Payne, Trans. vol. 50, no. 5, 1928, paper no. MH-50-3.

stocks in their storerooms. Now, instead of jamming the storerooms with materials that would lie there a long time, then taking them out and sending them to the different manufacturing departments, these companies schedule the arrival of materials so that they can be taken directly to the point where manufacturing starts, thus eliminating one handling. Within a few days these materials are probably out of the plant in the form of finished products.

Materials handling must be looked on as a part of the flow-of-work program. Walter R. Clark, works manager of the Bridgeport Brass Company, says he thinks the time has come to take materials handling out of the overhead column in factory accounts and put it in the production column, because where a man is moving material from one place to another, or where equipment is moving it, while no actual processing operation may be done, nevertheless one cannot separate the transfer of the material from the work of production. The men who are moving the material, or the equipment which is moving it, are vital adjuncts to production line.

How does this bigger conception of material handling affect the railroads? They are asked to transport material which a manufacturer receives from his supplier and which is considered practically in the plant when it is started from the shipper. Hence efficient service from the railroads enables the manufacturer to cut his inventories. It is claimed by the Ford Company, for instance, that they have just about a week's supply of material on hand. If the railroads delay shipments, however, such companies are "out of luck." Many companies are adopting this same plan, considering that when material leaves the shipper's plant it is practically within the control of the receiver, the railroad acting as an outside agent for the receiver. This plan makes the railroad, in effect, a moving storehouse and a part of the flow-of-work line in the manufacturing plant. That is why it is so important to have the railroads cooperate with manufacturing plants so that there is no tie-up of materials in transit.

When we tie this program in with motor-truck delivery of freight where plants have no railroad sidings, we have a chance to introduce further improvements. Instead of having material land at the railroad yard and sending a truck for it during the day, with all the delays incident to street traffic, if the motor truck, run either by the railroad or by some private agency, could get that material at midnight and leave it at the door of the plant in care of the watchman or a night crew, a most perplexing street-traffic problem would be solved. The plan would also help solve an important shipping problem.

In other words, we are getting down to the plan of having a thin but continual flow of materials through manufacturing operations at all times, and the railroad is almost as much a part of this program in the manufacturing plant today as the materials-handling service within the plant itself. The motor truck is likewise a part of the program, bringing in materials to keep the production lines fed in plants without railroad sidings. We all know what happens to schedules in any plant if the production line stops even for a few minutes.

Hence we must look at materials handling as a cycle extending from the time the shipper puts goods on railroad cars, or is ready to put them on, until that material arrives at the plant of the receiver, is put through his processes, and is ready to go to the consumer. It is therefore vitally important for the manufacturing plants and the railroads to get together and work out a comprehensive program of rapid, uninterrupted transportation service, because such a plan means lower costs, better production, and more successful meeting of domestic and foreign competition.

A. L. Struven.[6] We are interested in shipping via rail and lake, and we are working on the design of steamships to handle unit containers. We expect to handle take-off cars at our terminals at the Great Lakes and place in ship without any stevedoring cost; and I hope within another year we shall have some of these ships on the lakes.

[6] Chief Engineer, Terminals & Transportation Corp., Detroit, Mich.

### Author's Closure

Answering the inquiry of M. D. Lees,[7] the unloading of containers can be done in either of two ways. At present it is by lift cranes. The Eastman Kodak Co. at Rochester is perhaps one of the largest users of containers. They are taken to the place of business on a truck and either left on the truck while being loaded or taken off as desired. The Eastman Kodak Co. has a contract with a truckman who takes the containers to a crane at the railroad, where the lifting from the truck to the cars is done at no expense to the shipper. When the car gets to the other end of the line, the containers are lifted by a railroad crane and placed on a truck and taken either to a steamship line or to the place where the local delivery is to be made.

Another method by which a new form of car, still in the experimental stage, will be used, will make it possible to take the containers off the car without a crane but by a lift truck. Up to the present most of the loading and unloading has been to and from the truck, as the usual place of business, such as an office building or loft, is not adapted to receiving such a large container. At a factory having a platform the container is unloaded on to the platform.

Charles Schroeder[8] has asked how the containers would be removed from this freight car—by a lift truck, or by the truck running on the deck of a freight car. The lift truck is run under the container while on the car. Elevating the lift truck raises the container, which is then backed off the platform and put on to a specially devised truck. It is taken to the place of business on the truck and removed from it by means of another lift truck. The sunken rail is not used because the container is on feet.

In answer to a question as to the method of holding containers on the trucks, there are several methods. In trucking containers around New York City streets, they are sometimes held by cables which hook into eyes on the side of the containers. There is also a truck which has a hook on the side of the platform to engage the bottom of the container. A third plan is to have no fastening at all, and in places other than New York the containers are never fastened. The weight of the container load, between 5 and 6 tons, is sufficient to hold it on. An assembly of a tractor and trailer, the latter with a body holding three containers, has also been devised.

Answering James A. Jackson[9] as to the saving in cost effected by containers and other types of handling equipment, figures are available which give the experience of the shipper and the railroad.

S. J. Kirsch[10] inquires about the materials used for containers. The International Motor Company is using a container made of a light metal, but this is only for handling materials between the plant in Plainfield and another plant in New Brunswick. It is a lift-truck body which can be pushed off the chassis at the terminals. It is not used at all in railroad practice, nor can it be. Incidentally it is an adaptation of the so-called L.C.L. container mentioned in the paper for use on a truck.

[7] Eastman Kodak Co., Rochester, N. Y.

[8] Yale & Towne Mfg. Co., Stamford, Conn.

[9] Application Engineer on Elevators and Materials Handling Equipment, General Electric Co., Schenectady, N. Y. Assoc-Mem. A.S.M.E.

[10] Production Engineer, Armstrong Cork Co., Camden, N. J. Jun. A.S.M.E.

A container made of duralumin could not be used profitably in railroad service owing to the expense and to the doubt as to its durability. One is being tested in service, but it is not stiff enough to support the weight. There is also one of aluminum, but so far the experience of seven years points to a steel container with a special laminated-wood floor.

C. L. Freeman[11] asks if electric lift trucks could be used in place of hand lift trucks. With containers it is planned to use electric lift trucks exclusively. Hand lift trucks will not do.

Answering George W. Kelsey[12] in reference to ownership, all the containers are owned by the railroad companies. The shippers own no part of them. In other words, a low-side gondola car with a battery of six merchandise containers or twelve bulk containers is considered a piece of railroad equipment. There is no expense to the shipper for the use of the containers.

In reply to Monberg Nelsen,[13] the method of loading and unloading containers on or off a car is by a lift crane, where the volume is such as to make it more economical, or, as is now being worked out, by the use of an electric lift truck. In handling brick, the unit cost of crane operation with two cranes handling over 290 containers a day, including the cost of the two cranes and the track work, with amortization on a ten-year basis, and a crane operator, is about 19 cents per container. Amortization on a ten-year basis is probably much too low as the cranes will last much longer, and it is believed that the containers will also. No experience with the containers is available as a guide because they have been in use only six or seven years. The original containers, with one exception, are all in service, so that it is reasonably certain that their life will be ten years at least.

Cartons are packed into containers just as any package would be packed in a freight car, but with the exception that it is not necessary to use the kind of package required in a freight car. For instance, for a manufacturer in Rochester who makes carbon paper, a shipment of 8000 lb. of carbon paper, when put in shape to ship in a box car, makes 9200 lb. of freight, the added 1200 lb. being the boxes. The boxes cost $1.50 apiece, and there are eight of them. This manufacturer now packs the carbon paper in brown paper and saves the cost of the boxes and also saves the freight on the boxes.

[11] Industrial Power Representative, Consolidated Gas, Elec. Light & Power Co., Baltimore, Md. Jun. A.S.M.E.

[12] Assistant Professor, Industrial Extension Division, Rutgers University, New Brunswick, N. J. Jun. A.S.M.E.

[13] Chief Engineer, Mathews Conveyor Co., Ellwood City, Pa. Mem. A.S.M.E.

The brick containers, or any bulk containers, such as those for crushed stone, sand, or any material that can be emptied through the bottom of the container, obviously would not have feet, as it is necessary for a crane to lift them in order to open and close the unloading device. The merchandise containers have feet and can be used either with a lift truck or a crane, whichever is more desirable.

John A. Grove[14] asks if it is possible to make a container for sand so tight that it will handle clay or any very fine material. Bulk lime, which is probably as fine a material as any, is now being handled. It goes almost to a fine dust and is handled with an absolutely watertight bottom and top, so that there is no sifting at all. Although clay is at present put in bags to keep it from sifting out, an experimental container is under way. Fine sand is shipped in it. The lime container will handle clay because it is absolutely watertight. As to the use of containers now being sufficiently general to specify receipts of clay by means of containers, this depends upon the location of the plant and the shipping point. Mr. Grove is shipping from Georgia, and there are no containers in Georgia at present. There is no reason why these containers should not be used in Georgia. A manufacturer inquired recently about shipping gum, pitch, or tar in Georgia. We have devised an absolutely leakproof container in which he is going to ship this semi-fluid product, and in which he will reship it after refining.

It was brought out in the discussion that Montgomery Ward & Co. put their L.C.L. freight in cars for different transfer points, loading about six cars a day. It has been asked if it is possible for them to separate the contents of a car into different containers for the different railroads. Ultimately it is expected that this will be done. It is expected that companies making large shipments can load a container, making it a unit, and on one car put containers for six different destinations. These are to be taken to a transfer point for containers, and there transferred. Instead of subjecting the railroads to an L.C.L. expense of 62 cents a ton average, there would be a cost of 4 cents a ton for transferring the containers. In other words, the railroads will save the difference, and the shipper will get the benefit of a straight shipment in a container as in straight cars, and the use of less expensive packages than are required today for protection under the official classification requirements of container shipping. The container method of shipping is doing away with official classification requirements of every nature and description.

[14] Atlantic Refining Co., Philadelphia, Pa. Jun. A.S.M.E.

# Progress in Machine-Shop Practice

## Contributed by the Machine-Shop Practice Division

Executive Committee: L. C. Morrow, *Chairman*, Carlos de Zafra, *Secretary*, W. F. Dixon, J. H. Connolly, J. W. Hook, and W. W. Tangeman

ECONOMIC factors call forth the development of methods and equipment in any industry. It is equally true that pronounced advancement in production methods and equipment design affects economic trend. It is difficult to separate the two—to say where one leaves off and the other begins. Consider that important influence upon machine-shop practice during the past eighteen months—the almost universal recognition that successful competition depends quite as much upon the use of modern equipment as upon good management. Whether such recognition has done more to stimulate design than the new products of an inspired industry have done to obtain the recognition is a moot question, and for that matter is relatively unimportant. It is enough that the recognition does exist and that the metal-working industries have the advantage of lower production costs for the user, and increased equipment markets for the builder, of modern machine-shop equipment. It is significant that sales have been few among those equipment builders who have not modernized their product from the design point of view.

### Economic Factors Influencing the Metal-Working Industries

Similarly, there is a cooperative effect of the requirements of the equipment user and the inventive ability of the equipment builder that is revealed in more productive machines and tools with consequent mutual benefit in a business way. This condition is especially marked in connection with the automotive industry, wherein the search for ever lower production costs is a result of keen competition and the necessity for extremely large markets. It is not confined to the automobile builder, however, but extends firmly into any metal-working plant devoted to products made on mass production, and to a lesser extent into even the small-quantity, jobbing, and repair shops.

Because of the large markets required for our metal products it is advantageous that Europe is progressing toward economic stability. There have been worth-while improvements in business from England and Germany, and considerable improvement from France. Czechoslovakia remains a very good market, considering its size. South American consumption has increased. These statements apply to metal-working equipment and to automobiles.

Foreign markets are worth emphasis at this time because of the recession in the machine-shop-equipment business domestically during 1927—a recession not serious, but noticeable, and one that served to emphasize the over-capacity of the equipment shops, which has resulted in the extension of the lines of individual builders, thus multiplying the points of competition. To offset such expansion there have been few consolidations.

Other general factors affecting the metal-working industries are hand-to-mouth buying, increased commissions to dealers in some divisions of the industry, the requirement for sales engineers who are skilled in processing, the necessity for more accurate cost-accounting methods, and progress in standardization.

Hand-to-mouth buying has reduced inventories in some quarters and increased them in others. It has benefited the equipment builder in that respect, but has, at the same time, placed the premium of getting the business upon the ability to make prompt delivery. Thus the manufacturer with few lines and still fewer variations has had an advantage.

Increased commissions to dealers have raised the cost of sales, but have also spurred the dealers to increased efforts. Moreover, since not all of the increased cost could be passed to the consumer, on account of keen competition, the equipment builder has found it to his advantage to look to his own production methods and shop equipment.

The demand for sales engineers who are skilled in processing is a natural outcome of the search for better methods compelled upon the part of the user by competition.

More accurate cost-accounting methods must necessarily accompany campaigns directed at the lowering of costs. Despite the fact that in principle, modern equipment has decided advantages over equipment several years old, there are cost-accounting problems that must be solved to the satisfaction of the guardian of the purse strings. For example, how much shall be allowed for depreciation and how much for replacement in view of the evident shorter economic life and increase in cost of equipment of advanced design, greater productive capacity, and better quality? This matter of cost accounting has assumed such large proportions that equipment builders are actually undertaking to educate equipment users in its fundamentals.

Standardization, not alone in metal products but in entirely disconnected lines, has influenced machine-shop practice. We are in an era of standardization and simplification that is reflected in all products. It is bound to have—and has had—an appreciable influence upon methods and equipment. The progress in the field dominated by the machine shop has had some notable examples of successful standardization. Akin to this movement and to the process of simplification is the elimination of waste, the outstanding results of which are already known, but which is being carried further by reductions in the cost of product by the substitution of pressed-metal and welded parts for those formerly made by more expensive methods.

### Progress as Indicated by Changes in Machine Tools

Most of the progress in machine-shop practice is indicated by the changes in machine tools. The first machine-tool exposition under the National Machine Tool Builders' Association, held in Cleveland in September, was therefore an index of such progress. The exposition was important also as further establishing a delayed buying period that had already become noticeable as a result of the expositions of the American Society for Steel Treating. The exposition of this year was the largest collection of machine tools featuring new design—and under power—ever displayed. Its influence upon the designing engineers of the builders and the production engineers of the users was most pronounced. It was a mart as well as a display. It thoroughly impressed the users of machine tools as to the extent and the solidarity of the machine-tool industry, and doubtless served to convince the machine-tool builder anew of the importance of his industry to civilization.

Progress in machine-shop practice, aside from the generalities just dealt with, can be shown best by a consideration of the details of changes in design of machine tools.

The demand of the machine user for greater strength, greater

rigidity, and constantly higher speeds of production has been met by the builder with increase in weight, strengthening of critical sections, and a substitution of sturdier materials, especially in the more universal use of heat-treated alloy steels. Though the removal of great volume of metal is not of necessity a part of modern high-production methods, the ability of a machine to do so is, in a measure, a test of its capacity to withstand the shocks of high-pressure work without lowering its standard of accuracy and precision.

Anti-friction bearings have been incorporated extensively into the design of machine tools on rotating shafts, and in some cases on spindles, particularly on the spindles of drilling and grinding machines. Even on milling machines their use is quite common. At least one lathe builder uses them regularly on the spindle, and another supplies them as optional equipment. No standard practice in the application of anti-friction bearings has appeared. Some builders use only ball bearings, others only roller bearings, still others use both. On many machines the plain bearing has practically disappeared.

### Machine Drives

It is becoming more common practice to connect the rotor shaft of the electric motor direct to the first driving shaft of the machine through some form of compensating coupling. In many of the machines having movements of adjustment in several directions a corresponding number of motors is used, each motor driving the particular unit upon which it is mounted without reference to or connection with the other parts of the machine.

The unit-drive method has led to the wider control of power traverse and power setting by push button, a control that has been developed to a point of great precision. Electric clamping, controlled by push button, also has been adopted when practicable, particularly for clamping the columns of radial drills.

In spite of the growth of the method of driving through direct connection of motor to driving shaft, the method of transmitting power by means of a short belt or some form of silent chain remains the most popular. It permits considerable latitude in the matter of speed ratios, works well upon even very short center distances, and operates without noise. A check-up of half of the machines at the machine-tool exposition showed that approximately 57 per cent were so driven. Another drive suitable for short center distances, and finding favor, is the multiple V-belt type. There are now several applications, and the indications are that its use will increase.

While the automobile-type disk friction clutch is more generally used, there exists a difference of opinion, some designers tending toward the positive clutch.

One of the greatest advances made has been in positive lubrication. In many machines all important bearings are oiled from a central reservoir by means of force-feed pumps. Both the circulating system, in which a continuous flow of oil to the bearing and back through a filter to the reservoir, and the intermittent system that supplies a drop of oil to each bearing at stated and easily regulated intervals, are used. Flood lubrication is rather generally applied to gear boxes. Pressure-gun greasing is used on many tools for isolated rubbing points. Full force-feed oiling of a whole machine has been accomplished; either a circulating or a "one shot" system is used for the purpose. An oil purifier, of the type used on automobiles, has been applied to at least one make of machine.

The hydraulic medium for transmitting power has been adopted to a surprising extent. It has been applied to the auxiliary feed and traverse movements, where it is of especial value because of its flexibility, easy control, and low liability to derangement and breakage. Particularly rapid strides have been made in applying this type of feed to drilling machines, grinders, and broaching machines, although other types, including milling machines, have been so equipped. Of the two hydraulic drives in common use, the cylinder-and-piston type is the more frequently applied, although in some of the larger machines, having long traverse movements, a hydraulic motor is connected directly to a pinion in mesh with a rack on the moving part. In this way there are no limiting factors in respect to length of movement inherent in the drive.

### Developments in Design

Other developments that apply to the machines of individual type, or to the machines of individual builders, can be described sufficiently by name only:

The actual and contemplated adoption of hardened steel ways.

The increased use of interlocking devices on control mechanisms.

The increased use of safety devices, shear pins, slip frictions and similar devices.

Changes in plâner control to secure more rapid acceleration.

Dynamic braking on voltage control.

Further trend toward automaticity.

Use of progressive assembly in building large machine tools.

Increased use of ground taps and very accurately finished chasers.

Contour planing and turning, using thin sheet templets, and with automatic electric control of the tool.

Cold-rolling of thin sheets and strips, by means of rolls of small diameter, without annealing.

### Development of Machine Tools for Use in the Automotive Industry

Development of machine tools used particularly in the automotive industry deserves special mention, because of the influence of the industry upon machine-tool design in general, and because the automobile industry furnishes the greatest single market for machine tools. The developments have not been startling, in the way of new processes of a revolutionary nature, but changes have been constant, all tending in the direction of increased production and improved quality.

In machines such as the knee-type miller, there has been adaptation of the standard machine to special uses by means of additional spindles at whatever angle or in whatever position fitted the particular job in hand. In a somewhat similar way the special drilling head, with its spindles built to handle a particular job, and that job only, is being used in place of large multiple-spindle machines in which the spindles have to be adjusted for each set-up.

For certain types of drilling there has been considerable development along the line of three- and four-way drilling machines with enough spindles to drill all the holes in a transmission case or similar unit.

Turret lathes, both hand-operated and semi-automatic, are being more widely used. They have been improved by being provided with more substantial spindles and bearings, more convenient controls, and better lubrication.

The use of the grinding method of machining continues to increase, being particularly noticeable in connection with flat work and in honing. There is a noticeable tendency toward the adoption of the rigidly mounted hone, with the object of correcting out-of-roundness and taper. The latest types of machines on which the rigid honing heads are used provide automatic collapse and expansion of the heads. Originally designed for and used in the finishing of cylinder bores, the rigid-hone head is now being applied to the finishing of smaller holes, one example being piston-pin holes less than one inch in diameter.

A late addition to the line of crankshaft machinery is a lathe

in which the shaft can be driven from the center while both ends are turned. A bearing is used between each two throws of the crankshaft.

### Advances in Grinding Practice

Outside the automotive field, as well as within, the grinding process has been making great headway. New abrasives and new types of wheels have done much in the way of production. New bonds have permitted greatly increased speeds. Grinding of machine ways is an accomplished fact. Spindles are being subjected to an extra-fine grinding operation that gives a surface comparable to the best in automotive practice; considerably longer life is expected to result. Semi-automatic and full-automatic machines that put the work in place, perform the operation, and pass the finished piece on to the next machine are coming into the grinding field. In line with the general trend, more attention has been given to securing accuracy with a minimum of the operator's attention, even within remarkably close tolerances. Centerless grinding has made great strides, both in machine design and from the point of view of increased knowledge of the possibilities by the method. Semi-automatic, multiple-spindle, cylinder grinding has been developed. Worm-grinding machines have been introduced. Segmental grinding-wheel chucks have been placed on the market.

### Processes and Machines of the Year

Certain processes and certain types of machines have come to the front during the past year.

Arc welding has been developed to the point where it is making possible the use of structural shapes and slab steel instead of cast iron and steel for motor and generator parts, for machine bases and for other products. Hydrogen-arc welding has been introduced as a practical process, and the shop equipment for its use has been developed. Welding machines as a whole have been developed, so that the process is much less dependent than formerly upon human skill, thus placing the process within the positive group, adaptable to production.

Jig-boring machines have been much improved during the year. The advances in design have been very favorably received and, in spite of prices relatively high in comparison with those of other kinds of equipment, have found a ready market. Their advent has placed many older and less accurate machines in the obsolete class.

A new method of dimensioning chamber sizes in rifle barrels and a standard method of making and checking chamber and barrel gages within 1/200 of 0.001 in. have been discovered. By the use of this method duplicate chamber plugs may be made by several gage makers, without variation among the gages of more than 1/4 of 0.0001 in. in diameter and with a variation of 0 in length.[1] It is obvious that these methods may be applied to gages for other classes of work, and may be instrumental in obtaining the extreme accuracy toward which the machinery industries are tending.

The casting of locomotive frames with cylinders integral by a middle-western manufacturer has given rise to a need for large machine tools to finish these castings. To perform the necessary machining there has been built a large milling machine to perform in one setting the operations that formerly required a large planer, a large slotter, and a cross-cutting planer. The redesign has effected a material saving in cost.

Equipment for producing accurate gears has progressed in design. The process of burnishing after cutting, and sometimes after hardening, is prominent. Additional equipment for inspecting gears also has been made available. One manufacturer has devised a machine for inspecting a gear and at the same time making a record of any inaccuracies, which can be analyzed to determine the characteristics of the gear.

Finishing of machine tools, other machines, and miscellaneous metal products is undergoing development. Finishing of machines by the spray method, usually involving the use of lacquers, has been adopted by several manufacturers. To some extent conveying equipment has entered into this process. The anodic oxidation of duralumin is one of the new finishes used on products.

The processes involved in heat treating have received marked attention during the year. Certain nomenclature has been adopted as standard. Time and temperature control has been made more exact. Steels and their treatments have been improved. Among the hardness-testing instruments introduced is one that measures the load required to cause a diamond ball to be impressed a given and constant distance into the material being tested, with provision for correction for errors due to contraction of the parts in the machine and the diamond when under strain.

Among the individual machines introduced during the year that point the way to what may be expected, are:

An "offset" milling machine, making use of a circular table on which the parts being milled surround a cutter of large diameter, the centers of the cutter spindle and the table spindle being eccentric. The object of this design is to engage a large proportion of the cutter with the work.

A push-broaching machine for broaching flat surfaces usually milled.

A turret lathe that has an ingenious hydraulic chuck-operating device actuated by the coolant pump, and using the coolant as the liquid medium.

An automatic vertical turret lathe.

### Standardization—Research

Standardization, though influential, did not progress as rapidly as it should have during the past year in the machinery industries. The outstanding accomplishment was the standardization of spindle noses and arbors of milling machines. Aside from its value as providing standards, it demonstrated what can be done in standardization work by an industry or group.

T-slot standards, adopted during the year, were heartily welcomed. Their full effect will not be felt for some time.

Other standards have been adopted, and progress has been made toward the determination of still others. Announcements from the committees and societies concerned, and by the technical press, have kept those interested informed.

Partial standardization of the principal dimensions of a.c. and d.c. motors has been accomplished in foreign countries. To some extent individual domestic manufacturers have progressed along the same line, making certain dimensions constant for a.c. and d.c. motors, but as a group the motor manufacturers have done little.

Of research work within the industry, there has not been a great deal. Progress reports issued from time to time have given information concerning the work on gears being conducted at Massachusetts Institute of Technology under the auspices of the American Gear Manufacturers' Association and The American Society of Mechanical Engineers. Studies have been in progress concerning oils and cutting tools. Study of dynamic and static balance has resulted in widening the field for balancing equipment beyond the balancing of automobile cranks and flywheels to the rotating parts of all kinds of machinery.

The activities of the Special A.S.M.E. Research Committee on Mechanical Springs during the year covered the organization of a financial cooperative group, the preparation of the bibliography for publication, and the layout of experimental work

[1] A demonstration of this method was made by E. Pugsley at Frankford Arsenal and in New York City before the Technical Committee of the S.A.A.M.I.

for the year 1927–1928. The personnel of the financial group numbers forty-five, twelve of whom are spring manufacturers and the remainder spring users. Each of these firms contributed an average of about $150 to the research fund. The committee is now starting the experimental phase of its program, several candidates for the position of Research Fellow, who will conduct the tests, having been interviewed. Copies of the bibliography will soon be available.

It is hoped that more will be accomplished by research during 1928. A committee for the purpose of instigating projects for research has been formed by the Machine Shop Practice Division. Machinery has been provided for getting the work under way after the committee has made its recommendations as to the work to be done, the laboratories available, and the personnel desired. It is expected that the value of the results to be obtained will then be so evident as to greatly assist in the collection of funds.

### The Outlook for 1928

No one can predict with certainty what will be done during 1928. We may expect, however, to see progress along several lines, among them:

Still further use of hydraulic feeds and drives, anti-friction bearings, heat-treated alloy steels, pressed-steel and welded parts, automatic lubrication, safety devices, and automatic operation.

Development and adoption of more standards—for example, standards for nomenclature, initial machine speeds, motor speeds, electric-motor mounting dimensions, machine-tool capacity and performance, belt pull, and so on.

It is likely that foreman training, already well to the front, will be a subject of both experiment and progress during the coming year. It is gratifying that the foremen themselves are realizing the importance of their positions and are making persistent efforts to better fit themselves for their work.

There is still a feeling on the part of some members of the industry that skilled mechanics are no longer being made in quantities sufficient for the good of the industry. Other members feel that the supply is keeping pace with economic law—that the transfer of skill from man to machine has made relatively few mechanics necessary. No matter which viewpoint may prove to be the better, it is essential that the industry train boys for shop positions. From the ranks of these boys there will always emerge a number of skilled mechanics, who can be at least a nucleus on which to build in case of emergency. Others of the boys will become foremen. All of which indicates that attention should be given to apprentice training. There should be devised a system that will cause each manufacturer to contribute his share of skilled workmen and foremen to the industry.

There are predictions that at some time in the future we may expect radical improvement in cutting tools, an improvement which will cause the new tools to be so much more productive than those of today that the increased production will be comparable to that resulting from the introduction of high-speed steel. Whether such improvement will appear during the next year or within the next few years, is conjectural. The advent of a material, or a process, that would have such an effect would revolutionize machine-shop practice.

The activities of the Executive Committee of the Machine Shop Practice Division for the year consisted of the holding of sessions at the Spring Meeting and Annual Meeting; holding a joint meeting with the Metropolitan Section, at Newark; holding a National Meeting at New Haven in connection with the annual machine-tool exposition; the formation of a survey committee to instigate projects for research; and the preparation of this progress report. It is hoped that the service rendered to the machinery industries by these activities has been commensurate with the effort expended by the speakers and the Executive Committee.

L. C. Morrow, *Chairman.*

# The Development of Machine Tools from a User's Viewpoint

By F. C. Spencer,[1] Chicago, Ill.

*The author bases his paper on the experiences and practices of the Hawthorne Works of the Western Electric Company, whose development organization is charged with the selection of machine tools. This organization has adopted five standards which affect the design of machine tools: namely, minimum floor-space requirement; elimination of accident hazards by properly designed guards; reduction of physical effort by convenient operating arrangements; cleanliness; and appearance. The effect of these standards on labor is next brought out and is followed by a review of the motor-drive program which has eliminated all but individually motorized machines with motors generally located in the machine base. Examples of several individually motor-driven machines are given. There then follows an account with some details of construction of the development of better and safer punch presses, and machines for drilling small holes in thin metal. The paper ends with a discussion of the possibilities of the hydraulic drive and the importance of giving special attention in the design of all new machine tools to the matter of safety, maintenance, and facility of operation.*

WITHIN recent years the development of machine tools has progressed with great rapidity, and this has been particularly true of developments tending to increase the suitability of standard machine tools for manufacturing purposes. Much of this progress has resulted directly from the economic necessities of the machine-tool user. It is the purpose of this paper to consider the question of machine-tool development as it has been influenced by the user's demands, and especially in the light of the experiences of the Western Electric Company.

The term "machine tool," which was formerly employed to designate only such machines as were used in the tool room and machine shop, is now interpreted more broadly to include many machines which are built solely for production purposes. It is with machine tools of the latter class, such as screw machines, milling machines, drill presses, and punch presses, and particularly with their development, that the user is mostly concerned.

If we look backward and consider the machine-tool equipment available from ten to twenty years ago, we shall find that the manufacturing requirements of that period were met, not so much by improvements in the design of the machine tools themselves, as by the use of clever tooling, ingenious handling methods, and special-purpose machines designed by users to meet their particular needs. Very few machine tools designed for performing specific kinds of operations were available. In fact, for several years prior to the last decade the machine-tool industry seemed to be inclined to perpetuate the designs it had been building for years, and to make only minor changes in details from time to time. Furthermore, machines were neither designed nor built for high-production service, and consequently when so used were short-lived and costly to maintain. One reason for this may be found in the fact that the machine-tool builder has never been faced with requirements large enough to warrant quantity-production methods, and there has, therefore, been little incentive for him to speed up machinery or to build machines capable of high speeds.

During the last ten years, however, many improvements have been incorporated in machine tools of practically all types. In some instances radical changes have been made, but many of the improvements have been simply adaptations of features already "proven in" by years of service in other types of equipment. For example, it is not unusual today to see featured in machine-tool advertisements such statements as "roller bearings," "ball bearings," "wick oiling," "continuous pressure oiling," "hydraulic control," and "built-in motor drive," although only a few years ago these entirely practical features, which mean so much in the matter of obtaining continuous high-speed production, were conspicuously absent.

Many new types of production machinery have been originated within the last decade, and the demand for these indicates clearly the opportunity for the development of equipment more adaptable for certain kinds of machining operations than the general-purpose machine tool. It is being appreciated that the more nearly a general-purpose machine approaches a special-purpose machine, the more efficient and the more valuable for manufacturing purposes it becomes.

During this same period many of the larger users have taken an active part in machine development, and many improvements have resulted from suggestions originating with them. This has been true to a large extent of the automotive industry. C. F. Kettering[2] has very clearly stated the attitude of the machine-tool user in that field as follows: "The economic factor forced us to improve upon the productive machinery in every conceivable manner, never hesitating to scrap even a comparatively new and expensive machine when a still newer one was developed that would speed up production, cut overhead, save human effort, give greater safety to the worker, or improve the product." Today the builder welcomes, and in fact, solicits, suggestions, a condition quite different from that which prevailed fifteen years ago. This collaboration of the user with the builder in machine development is of the utmost importance to the builder, as it must be recognized that he must produce that which the user will buy. The user controls the situation and consequently if improvements are to be made he must assume his share of the development responsibility and cost. In buying additional machinery the user often specifies the production expected, knowing from a careful analysis of the factors involved that the demand is entirely reasonable, although considerably beyond the possibilities of existing equipment. The equipment finally developed is usually capable of greater production than the output specified.

The engineering and design of machine tools is strictly a function of the builder and should remain so. Not all users employ the kind of talent necessary for this work, and those who do usually have a sufficient amount of special equipment to design to keep this talent constantly employed without attempting to alter the designs of standard machines or to develop new types. In order that satisfactory returns may be realized from the investment in machine tools, however, it is imperative

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[1] Assistant Superintendent, Manufacturing Development, Western Electric Co., Hawthorne Station, Chicago. Mem. A.S.M.E.

Contributed by the Machine Shop Practice Division and presented at the Annual Meeting, New York, N. Y., Dec. 5 to 8, 1927, of The American Society of Mechanical Engineers.

[2] *American Machinist*, vol. 66, p. 801, May 19, 1927.

that the user assist the builder by furnishing all the manufacturing information necessary to produce machines which his experience has taught him will more adequately meet the requirements of continuous quantity production.

## Development Organization

In the plants of the Western Electric Company a large quantity of medium-sized production machinery is needed to produce the enormous number of parts required every year for the manufacture and maintenance of the telephones and associated equipment of the Bell System. The problem of manufacturing this equipment economically depends for its solution mainly upon the machine tools selected for the job. The magnitude of the problem will be more fully appreciated if it is realized that the telephone equipment manufactured by this company consists of 13,000 different kinds of apparatus assembled from 110,000 different component parts. For several years it has been necessary to purchase or build from two to three million dollars' worth of machinery per year for the purpose of reducing manufacturing costs or for increasing capacity.

The selection of the machine tools for this job is one of the functions of the development organization at Hawthorne. This organization originated some twenty years ago when the demand for telephone equipment, although much smaller than it is today, was constantly increasing year by year. This increasing growth made it necessary to re-analyze each job frequently and to revise manufacturing layouts so that advantage might be taken of the larger requirements to make use of more productive equipment. It became evident that standard manufacturing methods were in many instances not suitable for manufacturing interchangeable parts in large quantities. A few experienced engineers, therefore, were assigned to the job of studying the problem in detail, and from this small beginning grew the present development organization, consisting of several hundred engineers whose function it is to study constantly every factor affecting the cost of production from the raw material to the finished product. About 35 engineers of this group are employed in the study of machining methods and the standardization of machine equipment, and about 85 designers are required to provide the designs for special-purpose machinery and changes in design or additions to standard machines when necessary to meet the requirements of this company.

These engineers develop all machining methods and select the standard machine tools which are required to meet the production schedule. They keep in close touch with builders of standard machines and, because of their more intimate knowledge of manufacturing conditions and requirements, have been of considerable assistance to the builders in developing machines superior to previously existing models.

The Western Electric Company has been a pioneer in this coöperative development work, and the records are replete with accomplishments. Policies governing the design and construction of machine tools of all types have been established.

## Machinery Standards

The standards adopted by this company affect the design of machines with regard to both their economic and humanitarian aspects and include the following:

1 Minimum floor-space requirement
2 Elimination of accident hazards as far as possible by properly designed guards
3 Reduction of physical effort by the provision of convenient operating arrangement
4 Cleanliness, secured by preventing machine and cutting lubricants from leaking or being thrown from the machine
5 Appearance.

To meet established standards satisfactorily, manufacturing machinery must be compact so as to occupy as little floor space as possible; it must be ruggedly designed to insure accuracy; it must be efficiently lubricated to reduce maintenance; all parts must be easily accessible, though moving parts should be enclosed or properly safeguarded to remove accident hazards; and the machines should be arranged for individual motor drives, preferably with the motor located in the base. They must conform to the latest and best practice with respect to materials, bearings, gears, and chains, and the workmanship must be of a high order. All of these requirements are incorporated in most tool-room machines, but until all production machines are built in accordance with these general specifications there will continue to be opportunity for improvement. To insure a standard of high quality the Western Electric Company finds it necessary to dismantle a large percentage of the machines bought so that they can be thoroughly inspected and replacements made or workmanship improved, if necessary, before the machines are placed in service.

## Consideration of Labor in the Design of Machine Tools

It should not be inferred that all of the standards adopted by the Western Electric Company meet the approval of all builders nor even of all users. Machine standards depend largely on the point of view, and the point of view in a manufacturing plant is a limited or a broad one, depending on the type of management. The importance of the economic factor in determining policies is well recognized. However, a management whose policies do not provide attractive as well as safe working conditions has been blind to the economic value of them.

A few years ago when this country was in the midst of great business activity and a shortage of labor was acutely felt in all localities, the company was faced with the problem of maintaining an operating force of approximately forty thousand persons. An analysis of the labor situation in the territory from which the Hawthorne Plant must draw its shop help indicated that there were approximately six hundred thousand persons in the class considered adaptable to the company's lines of manufacture. In this territory are several medium-size plants each drawing its requirements from this supply. It was estimated that the company would be obliged to select its force from about twenty per cent of the total, or one hundred and twenty thousand. Considering the various classes which it is necessary to employ, it is a difficult task to select a force of forty thousand from so small a number. The policy of selecting only the highest type of help was not relaxed, however, and each individual employed was required to pass a physical examination. During this trying period the company was able to keep a satisfactory operating force and to hold the labor turnover remarkably low. There is no question but that the unusually satisfactory operating conditions and shop environment were largely responsible for attracting and holding a high-grade class of employees. The company is convinced that environment has a great deal to do with health and contentment among employees, and consequently helps reduce the labor turnover.

The design of manufacturing equipment is influenced to a large extent by these considerations. Several years ago when the first multi-story buildings were erected at Hawthorne, the only equipment on hand and obtainable was belt driven, and the group method of driving was adopted as being the best available at that time. The belts and overhead shafting, pulleys, and motors obstructed the light, increased the hazard, and made all departments so equipped gloomy places in which to work. A typical belt-driven hand screw-machine department is shown in Fig. 1. Having provided light, airy buildings, the man-

agement was not content to have them filled with this objectionable equipment.

### Motor-Drive Program

Up to 1914 very few machine tools were available with well-designed motor drives. In that year it was decided to motorize the entire plant consisting of about forty-five hundred machines. The plan adopted involved, first, the development of individual motor drives for each type of belt-driven machine considered sufficiently modern and suitable for manufacturing purposes, and the replacement of all types of machines unsuited to such drives; and second, the policy of purchasing only motor-driven machines for additional capacity.

The motorization of the belt-driven machinery involved a great deal of expense for design and construction work but has now been completed. How well this program has succeeded is shown by reference to Fig. 2, which is a photograph of the hand

Fig. 1 Belt-Driven Screw-Machine Department

Fig. 2 Motorized Screw-Machine Department

screw-machine department referred to above after motorization. During these thirteen years progress in the machine-tool industry toward properly guarded machinery and well-designed motor drives has been slow, and consequently it has been necessary to keep several designers and a large force of mechanics on this class of work constantly to take care of the additional equipment bought to increase manufacturing capacity.

The second phase of the plan has presented the most difficult task of the motorization problem—that of persuading the builder to design and build his equipment in such a manner that it could be belt or motor driven at the option of the purchaser. In 1914, when the plan was launched, builders were not inclined to regard individual motor drives seriously, and the only arrangements offered were makeshifts. It has frequently been necessary to hold up purchases of additional equipment until a sufficient quantity could be ordered to induce the builder to furnish the design wanted. This is well illustrated by the development of the motorized milling machine.

The problem of motorizing belt-driven milling machines was

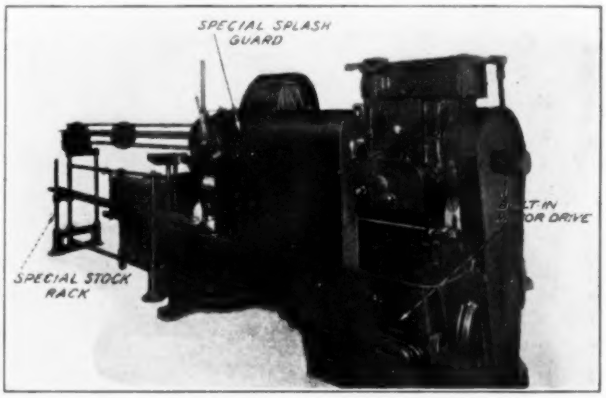


Fig. 3 Small Multiple-Spindle Screw Machine with Built-In Motor Drive

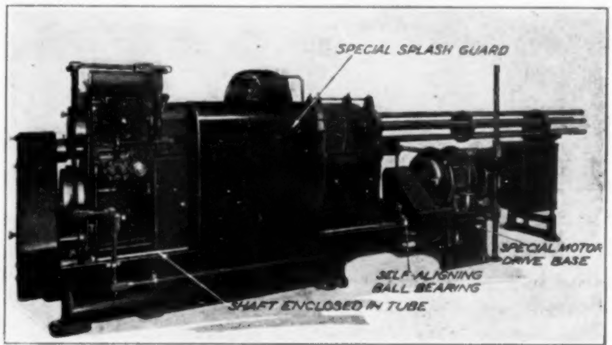


Fig. 4 Large Multiple-Spindle Screw Machine with Western Electric Co. Design of Motor Drive

attacked by locating the motors on brackets in the rear of the machines. This resulted in an increase in the floor space occupied, and indicated clearly that the future development of the milling machine would involve the incorporation of the motor in the base of the machine, totally enclosed, and properly ventilated. This idea was submitted to a few of the largest milling-machine builders, who, however, did not consider it advisable to change their line and offer it to the market in general, but expressed their willingness to build a certain minimum quantity. To do this it was necessary for the company to hold up purchases until a number of machines could be ordered sufficient to warrant the builder in changing the standard design. When these new machines with the built-in motors were finally installed the arrangement was found to be highly satisfactory, and the scheme has since been adopted by all the leading builders.

I am told that the demand for motor-driven machines of all types at the present time amounts to about 80 per cent of the total production.

### Screw-Machine Motor Drives

In addition to doing away with a forest of belts and overhead work, an endeavor has been made to limit the heights of the

machines, as it would obviously be inconsistent to go to the great trouble and expense involved in the motorization program and then to permit the machines themselves to obstruct the light.

Late-model multiple-spindle screw machines, for example, ordinarily furnished with the motor on top, are arranged with motor drives built in or on a special bracket so located that the height of the machine is not increased, and are a radical departure from standard equipment. The small machines have the drives built in the bases as shown in Fig. 3. In the case of some of the larger machines the motor is located at the stock end of the machine on a special base, Fig. 4. A chain connects the motor to the drive shaft which extends through the pan of the machine and drives the spindle at the other end by means of a second chain. The shaft is mounted on self-aligning ball bearings and is completely enclosed in a tube. With this construction not only has the height been reduced but the motor has been placed in a more accessible position, the floor load has been more evenly distributed, and the vibration appreciably reduced. Also a two-speed motor is used instead of the single-speed motor usually recommended, thus providing a wider range of speeds without changing chains or sprockets. The specifications for these machines included several other special features such as special stock reel, stock and control apparatus support, special attachments for threading in the second position, arrangement for revolving all tools at one time, and ball thrust bearings —altogether about twenty items, which, although adding to the cost of the machines, provided compact, well-arranged units which fill the operating requirements much better than the standard machines.

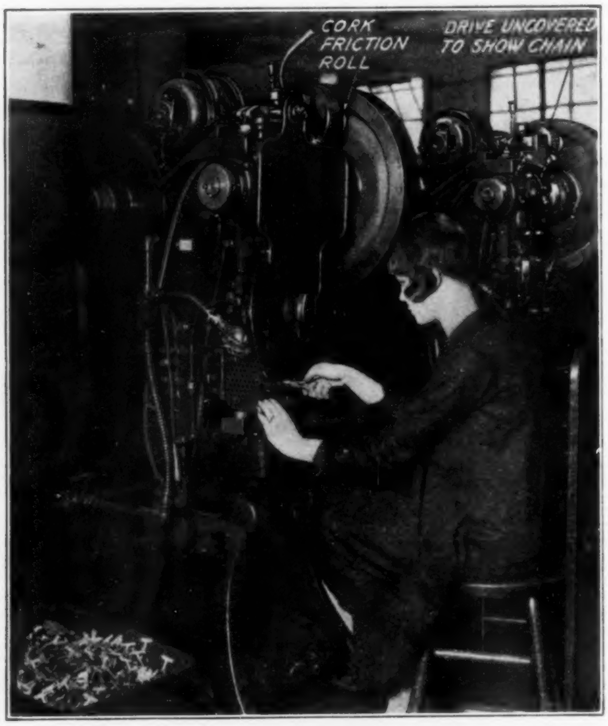


Fig. 5 Punch Press Embodying Several Western Electric Co. Design Features

One of the remaining groups of belt-driven machines which it is expected will soon be replaced consists of the one-inch and over-hand screw machines and turret lathes. A recent investigation of machines of this class reveals the fact that there is no motor-driven machine on the market with spindle speeds as high as are now being obtained on belt-driven machines. Some of those considered provide about half the speed now being used. Probably the reason for this is the difficulty of providing high speeds with geared heads. If this is the case other means should be taken by the builders to provide a range of speeds sufficient to handle economically parts such as those used in telephone apparatus.

## Punch Presses

There is probably no manufacturing machine that has undergone less change since the early designs than the punch press. Credit must be given to those who have had the vision and the courage to depart from conventional designs and to bring out low under-drive machines capable of high speeds. For blanking operations these presses are superior to gap-type presses because the ram is guided more satisfactorily and there is very little chance of misalignment of the tools. In the gap type the frame opens up slightly with each stroke of the press, and more expensive sub-press tools must be built to overcome this inherent fault. For second-operation work, however, the gap type is preferable, but in most cases the designs could be greatly improved.

In a plant using hundreds of medium-size presses and blanking and forming millions of parts per year, it is of the utmost importance, first, that these machines be safe to prevent injury, thus obviating lost time and a demoralized morale, and second, that they be constructed so that maintenance will be low in order that they may be kept constantly active. Western Electric Company punch presses are individually motor driven, having incorporated in their construction a special design of friction motor drive (Fig. 5); the bearings are bronze bushed throughout and the crankshaft bearings are split on an angle so that the upper bearings in the frame take all the upward pressure and the caps none (Fig. 6). The crankshaft is made of heat-

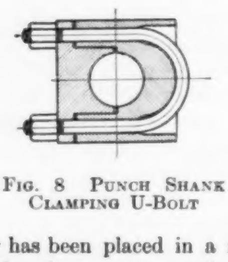

Fig. 6 Crankshaft Bearing, Punch Press

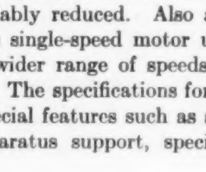

Fig. 8 Punch Shank Clamping U-Bolt

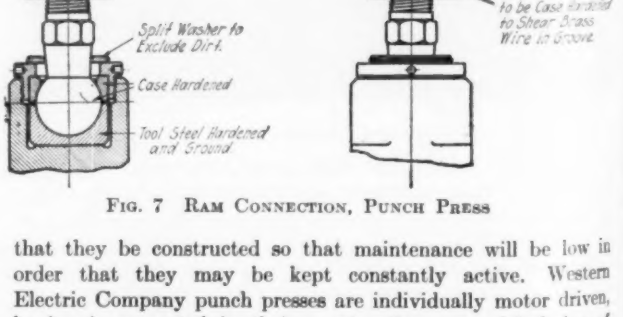


Fig. 7 Ram Connection, Punch Press

treated chrome-nickel steel as a matter of safety. The ram connection is provided with a shearing ring to protect the press from overload and the arrangement is such as to permit easy replacement of the ring whenever necessary. (Fig. 7.) A U-bolt is used for clamping the cap against the punch shank, as shown in Fig. 8. U-bolts are used here because they are easier to replace in case of breakage than the usual studs. The clutch is of the rocking-key type. The flywheel, which is mounted on ball bearings, is provided with several key-locking grooves to effect a minimum of clutching time. (Fig. 9.)

It is common knowledge that the punch press is one of the most difficult machines to guard efficiently without reducing output. These presses are completely guarded, including a balanced swinging gate operated by the foot treadle in such a manner that it is in place in front of the die space before the clutch is tripped (Fig. 5), and side gates to prevent the operator from reaching around the front guard. These are so arranged that when swung open the clutch rod is locked and the press cannot be operated.

The flywheels are webbed so that there is no chance of anything getting caught in them as is possible when spokes are used. Also the webbed wheels eliminate the usual flicker of light due to the rotation of a large number of spoked wheels. This has reduced fatigue and helped eliminate accidents. Punch-press accidents at Hawthorne are extremely low; in fact, the hazard has been practically eliminated.

To secure clean operating conditions a great deal of attention

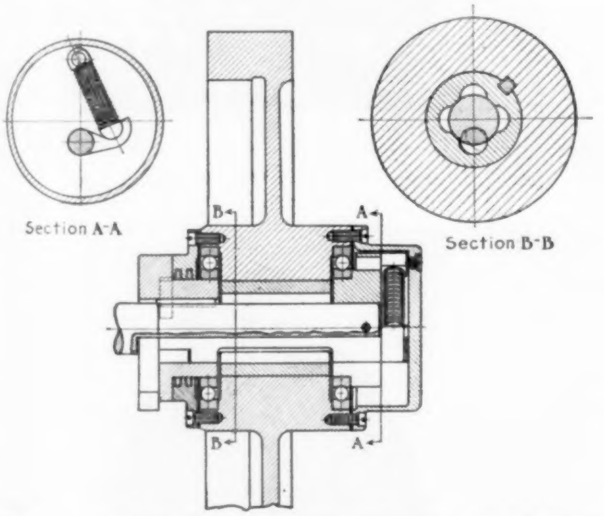


FIG. 9 SECTION THROUGH FLYWHEEL AND CLUTCH, PUNCH PRESS

has been given to preventing oil from leaking out of machines or being thrown off by revolving or reciprocating parts. Wipers and shields are required to obviate this. Punch presses, for example, are provided with shields (Fig. 5) to prevent oil from the crankshaft from being thrown on the operator.

### DRILLING MACHINES

Many well-designed high-production semi-automatic drilling machines are available for automobile parts and larger, but equipment for drilling small holes through comparatively thin material has undergone but little change in many years. The only important improvement that has been made is the increase in the spindle speed by the adoption of ball bearings. The aim seems to have been to provide machines for small work with relatively high drilling speeds with the idea of securing more nearly the same cutting speeds obtained with larger tools, though so far as the reduction in the cost of drilling small holes is concerned, this has never been an important factor. It could be shown very readily that the amount of time saved due to the higher drilling speeds is a very small percentage of the amount of time required for the complete operation of loading

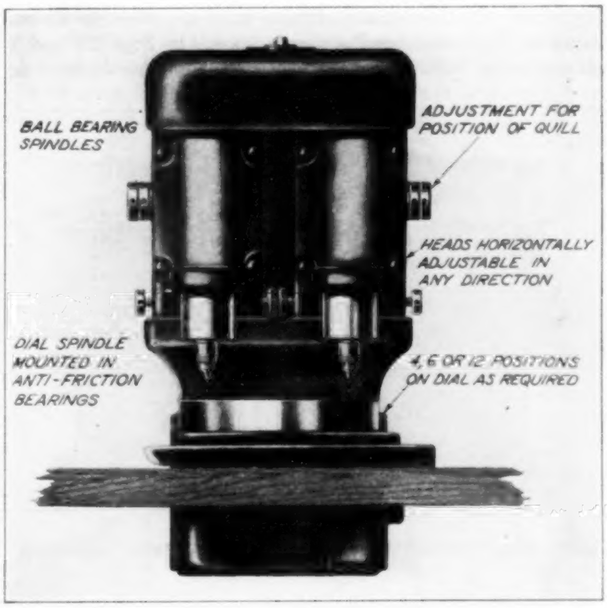


FIG. 10 TWO-SPINDLE AUTOMATIC DRILLING MACHINE, BENCH TYPE, DIAL FEED, FRONT VIEW


FIG. 11 TWO-SPINDLE AUTOMATIC DRILLING MACHINE, BENCH TYPE, DIAL FEED, SIDE VIEW

a jig, drilling, and unloading. It is true that automatic feeds have been developed, the principal advantages of which have been to reduce fatigue. They are a step in the right direction, however.

In the drilling of small holes at, say, 8000 r.p.m. through thin stock it often happens that, due to the nature of the work re-

quiring the loading and unloading of jigs and other handling, the drills are cutting metal only a small portion of the time; in fact, on some jobs less than ten per cent. So far as the author is aware, there is on the market no general-purpose machine suitable for small work in which the attempt has been made to cut down appreciably the time lost due to handling. For this reason the development engineers of the Western Electric Company have suggested a design shown in Figs. 10 and 11 which can be built with one or more spindles as desired, and

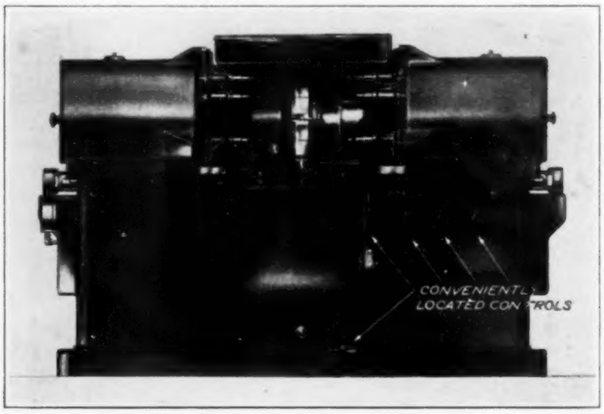


Fig. 12 Horizontal Duplex Semi-Automatic Drilling Machine, Front View

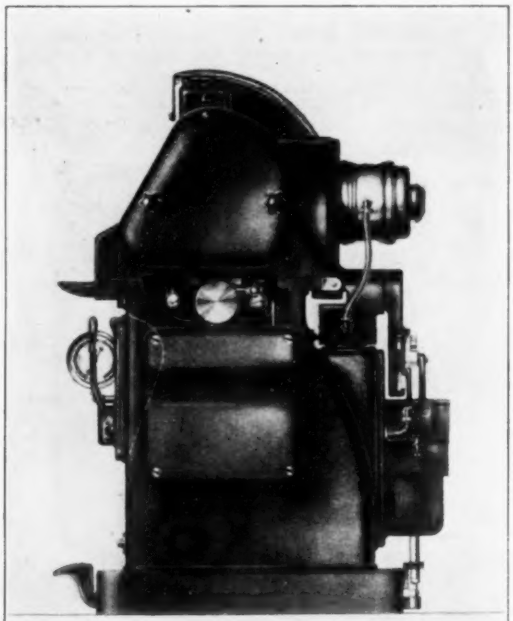

Fig. 13 Horizontal Duplex Semi-Automatic Drilling Machine, End View

which is provided with a dial for carrying the work to the drilling position by an intermittent motion, the drills being fed to the work by means of cams. The design shown in the illustration is that of a bench-type machine which is being developed at the present time. The driving and operating mechanism is entirely enclosed and adjustments are provided so that changes in speeds and feeds and the time of a drilling cycle may be varied as required. With this machine the operator will not be obliged to

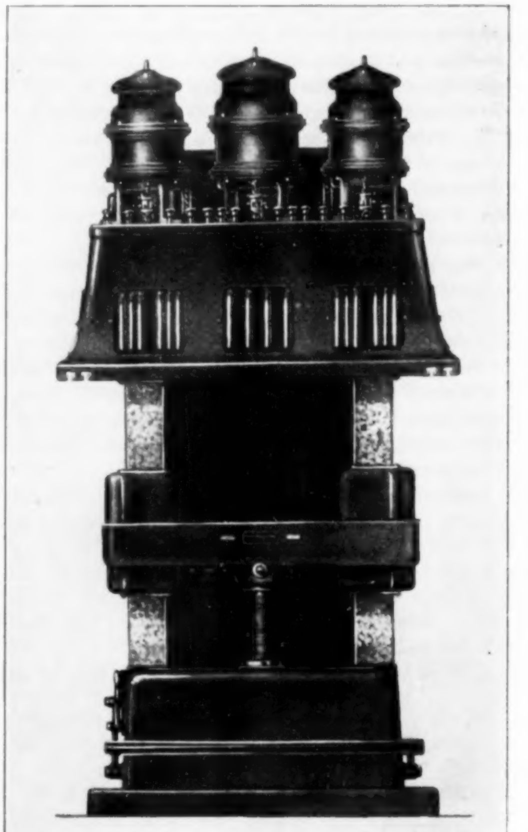

Fig. 14 Multiple-Spindle Drill, Front View


Fig. 15 Multiple-Spindle Drill, Side View

handle the jigs nor hand-feed the drilling spindle; her hands will be free for the sole purpose of loading and unloading. Even this labor may be eliminated on large production jobs by the use of automatic feeding and ejecting devices.

Another type of drilling machine which is being developed is shown in Figs. 12 and 13. This is a double-opposed machine with two heads, each carrying several spindles, which can be fed to the work from opposite sides. The work is held in a turret mounted on a horizontal axis in the center of the machine. The turret is hexagonal, each side of the hexagon carrying a fixture, and rotates intermittently, locating each fixture successively in line with the drill spindles in the opposite heads. The drilling heads are moved to and from the work hydraulically, arranged with rapid approach and correct drilling speed and quick return. It is expected that this machine can be used for drilling, burring, and tapping, and also for multiple drilling when required, simply by providing multiple drilling heads to be driven by the various machine spindles. The operator will sit in front of the machine and control it by means of a foot treadle. As long as the treadle is depressed the machine will continue to function, but as soon as the foot is removed from the treadle the machine will stop. The operator's task will be simply to load and unload the fixtures as they successively reach the position in front of her.

These drilling machines are shown, not because of their novelty, but principally to indicate the needs of a large manufacturer of small interchangeable parts in this machine-tool field.

A recent investigation of the available multiple-spindle vertical drilling machines with power feed, suitable for use on metal or wood, resulted in a decision that it would be necessary to design a machine in order that the desired operating conditions and maximum output might be obtained. Figs. 14 and 15 show the front and side elevation of this machine. Thirty-two spindles are provided, driven in groups by three vertical ball-bearing motors. The travel of the head to and from the work is accomplished hydraulically.

It is proposed to use cluster boxes having all spindles properly located for the job in hand so that the time of changing from one job to another will be a matter of a comparatively few minutes. For wood, higher-powered motors will be used as the drill spindles will rotate at speeds up to 8000 r.p.m. and the motors will be more heavily loaded. For this class of work it is highly important that no oil shall leak from the drilling-spindle bearings on to the wood parts. The ball-bearing spindles in the cluster boxes, therefore, will be provided with special oil retainers.

No user would prefer to design and build his own machine tools, and the Western Electric Company is no exception. The time spent on such work could be used to advantage on special-purpose machinery of which a large amount is required. It is found necessary to do so, however, on account of the relatively small number of different types of standard production machines available in the sizes used in the telephone-manufacturing business.

### Cost of Installation and Guards

The purchase price of machinery is never the entire cost. Often the cost of installation, including guards and electrical equipment, amounts to several hundred dollars. Much of this could be saved if the machine builder would build into his machines fuse boxes, switches, light brackets, and the necessary conduits, and would provide adequate and well-designed guards. This matter has been given more attention of recent years, but it is still found necessary to buy many machines on which these important features have not been provided.

Fig. 16 illustrates the electrical equipment and guards which had to be provided for a machine recently bought. In this case the additional equipment cost about ten per cent of the purchase price.

### Possibilities for Future Development

It is claimed that hydraulic feeds make possible higher cutting speeds and longer tool life; but whether or not this is true, there are advantages sufficient to justify the adoption of the hydraulic method of operation wherever possible. In the first place, the use of the hydraulic means for controlling, timing, and transmitting motion does away with the necessity of gears, cams, or screws, and the bearings and shafts on which they are mounted; consequently the maintenance by comparison would be extremely low. Another advantage is the exceptional flexibility of the system, it being possible to obtain very easily any speeds in either direction, or any variation in speed in either direction.

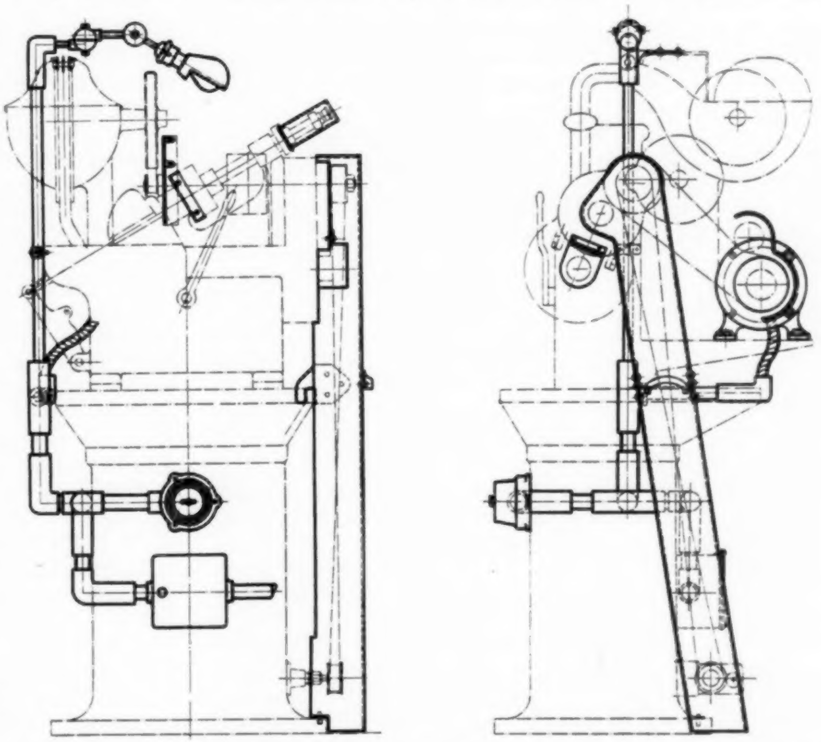

Fig. 16 Standard Machine with Electrical Equipment and Guards Installed by User

The advantage of the hydraulic system in the operation of punch presses would seem to be obvious; the length of stroke could be varied readily from a very short one, such as might be used in the high-speed blanking of small parts using an automatic feed, to a long stroke for forming or drawing operations. The speed of reciprocation could probably be as high as that usually obtainable with the crank style of press.

For small screw-machine work it would seem to be entirely practicable to design a vertical screw-machine unit which could be mounted singly or in multiple on a suitable frame and which

would take up much less space than the usual type. A unit of this type could be designed which would have a larger output than the present types of machines. There are some German and Swiss screw machines of small sizes on the market, but there is no machine built in the United States suitable for high production smaller than a No. 00 B. & S. automatic, which, including the stock rack, occupies about twenty square feet of floor space. This should be sufficient for about six units built vertically.

Furthermore, an attempt should be made to design screw machines capable of finishing each part completely instead of requiring additional work to be performed on them as is now necessary on a large percentage of screw-machine products.

### Conclusion

In conclusion, the author would like to emphasize the importance of giving special attention in the design of all new machine tools to the matter of maintenance, facility of operation and safety; and he would also emphasize the need of more semi-automatic production machinery.

*Maintenance.* By the use of anti-friction bearings and centralized oiling systems it is possible to increase speeds and to reduce the wear and tear on machinery to a point where the saving in the cost of production and by the elimination of losses incident to shutdowns for repairs will more than pay for these features.

A further means of reducing maintenance would be the reduction in the amount of mechanism by a liberal use of motors and by hydraulic operation, both reciprocatory and rotary.

*Facility of Operation.* A machine that is designed and constructed in such a manner that it is difficult to operate is no credit to the designer. There is little excuse for a machine of this kind. It is an indication of incomplete planning. Controls should require the minimum of physical effort, and the work of handling the product to and from the machine should be so easy as to result in as little fatigue as possible, even though these movements be repeated many times during the working day.

*Safety.* So much has been written on the guarding of machinery that the omission of guards by a builder would seem to indicate a disregard for the safety of the worker. It is probably due, however, to his hesitancy to increase the price of his machine sufficiently to cover the cost of the guards. The user should expect to pay for guards and should insist upon their being well constructed. It costs considerably less to have them built with the machine than to design and build them afterward.

*Semi-Automatic Production Machinery.* We would do well to encourage the design of more semi-automatic machinery for specific operations. There is an almost unlimited opportunity for the development engineer and the machine-tool designer in this production-machinery field, especially in the design of machines for the manufacture of small parts. Accomplishment in developments of this kind will be expedited if the machine-tool builder and the user will work more closely together, each assuming his share of the responsibility. This cooperative effort will result in benefit to both to a maximum degree.

## Discussion

L. D. Spence.[3] The work necessary for the manufacturing development department of the Western Electric Company at Hawthorne Station to perform in maintaining the machinery standards set forth by them, because of the nature of their work, places them in a position to view the machine-tool builders' products from a somewhat different angle from that of the average machine-tool user. The large production of small duplicate parts necessary in the manufacture of telephones and other electrical equipment enables certain features to be applied to machine tools that would assist in increasing the production of this class of work, and very often entirely special equipment is necessary to produce the maximum production possible for the operations to be performed.

Probably no class of manufacturers appreciates more fully than the machine-tool builders the call to cooperate fully with manufacturers who are engaged in mass production. In mass production there are, of course, some general lines of work that a machine could be designed to carry out, and such a machine would fit a large range of this work. In some respects it might not get the highest production for the specific job in hand; and the problem resolves itself into making a special machine, or into adapting the standard machine.

The past fifteen or twenty years have shown a cooperation between mass-production manufacturers and machine-tool builders that has brought forth wonderful results; and it is the writer's belief that as time goes on this cooperation will be strengthened, as each party to the arrangement will be urged on by this cooperative demand. More and more the manufacturer of standard machines realizes the necessities as just mentioned, and in order to fill more fully the requirements, efforts are constantly being made to build a standard or base machine to which attachments can be fitted that will fully meet the needs of the customers engaged in the various classes of work.

When the highest production is desired for the operation of a certain class of work, careful thought must be given to the loading and handling time. This time is often referred to as idle time. The machine-tool manufacturer has, during the last few years, given much thought to this in the design of machine tools, and at present we have the automatic milling machine, high-speed automatic screw machine, high-speed presses, and other machines suitable for more rapid production of interchangeable parts.

The machine-tool builder must, however, design his products so as to meet the requirements of various classes of work within the capacity of the machine. If machine tools are not carefully designed along this line, their use may be limited to firms which have only that class of work for which the machine is best adapted.

That portion of the paper referring to the progress made by the development department in connection with individual motor drive is very interesting. After a visit to a department of the Western Electric Company equipped with motor-driven machines, it is readily appreciated that the department is better arranged as far as light and working conditions are concerned, aside from the question of saving in maintenance cost of the overhead works and belting. Yet some classes of machine tools arranged in this manner are often more expensive than those designed for countershaft drive; and, as many machine-tool users are not ready to consider the individual motor drive, it makes it necessary for machine-tool manufacturers to build both types.

When reviewing the work performed by firms engaged in the manufacture of small parts in large-quantity production, it will be found that many special machines are used—machines designed for the operations necessary, such as drilling, etc. However, before the machine-tool builder can design new machinery to meet the requirements of this class of work efficiently, the extent of the field must be investigated in order to determine the extent of the usefulness of a machine of the design required.

Many special drilling, milling, tapping, and other machines have been designed by various machine-tool manufacturers; and, while they are very efficient on the class of work to be performed, their sales have been small as they cannot take care of the range or variety of work requiring the same operations.

A semi-automatic drilling machine having five horizontal spindles, each controlled by a cam, is efficient when producing work

[3] Brown & Sharpe Mfg. Co., Providence, R. I.

within its capacity. It is equipped with five drilling stations and its camshaft is so timed as to permit theun loading and reloading of one station while the remaining four spindles are drilling. A machine of the type referred to is suitable for the drilling of small parts of a shape that can be held in the holding fixtures.

Semi-automatic drilling and tapping machines having vertical spindles are also used to some degree. These machines have an automatic arrangement for indexing the circular table and, provided the shape of the work permits, a magazine can be arranged, thereby making the machine fully automatic.

Machine tools for other machine operations have been designed and offered to the user, and no doubt there is need for more high-production machine tools for this smaller work.

It would seem difficult for the machine-tool manufacturer to meet the requirements of the special equipment found necessary in the manufacture of watches and clocks and other lines in view of the efficiency of the special equipment now in use by firms performing this class of work.

The writer has in mind one firm engaged in the manufacture of a small article which required several milling and swaging operations. Because of the enormous quantities manufactured, special milling machines were designed and equipped with magazine loading and ejecting mechanisms. Seventy-six of these machines were used for four milling operations and required the attention of but four operators and two helpers.

The swaging machines were of standard design and each was equipped with a magazine. Thirty-two of these machines were operated by two operators and one helper. The average machine-tool user having work requiring swaging operations may not have a sufficient quantity of any one part to consider the feature of magazining blanks, as usually a change in a part necessitates a complete change in the magazining arrangement.

It would perhaps be difficult to find another manufacturer who would have a milling problem that can be worked out as efficiently as the work performed by the 76 milling machines in the plant referred to.

Our knowledge of the development of special equipment used in the mass production of these small parts should be of great assistance to the machine-tool builder in his endeavor to cooperate with such manufacturers in trying to arrange the standard types of machine tools so as more nearly to meet the requirements of all.

F. O. Hoagland.[4] In going through the Hawthorne plant of the Western Electric Co., it is quite evident that considerable ingenuity has been used in bringing about these developments that the author has described. I have personally seen several of them, and the job is well done.

The author comments upon the advisability of taking the motors off the tops of the machines. I have found it advantageous, however, on vertical-spindle machines to put the motor on top for the very reason that it gives a multiple-speed motor the advantage of having the highest speeds direct without any gear connections. I think in such a case it is not only justified but it is very desirable. On the other hand, when such conditions do not exist, I think the motor ought to be down in the base or as near to it as possible.

The author mentions obtaining higher speeds in belt-driven hand screw machines than in the motor-driven machines. Direct connection between the spindle and the motor for the higher speeds would make it possible to obtain almost any speed desired.

In regard to punch presses, I think the author's point about the web flywheel is very good. It eliminates the flicker he speaks about, and last, but not least, the chances of getting caught are less.

[4] Pratt & Whitney Co., Hartford, Conn. Mem. A.S.M.E.

The author does not see any particular advantage in high-speed small drills, and I think he is right as far as production is concerned, but it tends to eliminate breakage of the small drills.

The hydraulic-fed presses will undoubtedly come to the front. It is only a question of cost, or mainly so, but I do trust the day will come some day when the demand will outweigh the difference in cost.

In his conclusions the author refers to lubrication. As has been stated many times, 75 per cent of all breakdowns in machine tools are due to the lack of oil. The operator is not going to look around for hidden oil holes or oil cups but he will put the oil in a central place or have somebody else do it, and this will increase the life of the machine considerably. A wick oiling system must be given serious consideration because after the machine has been in the repair man's hands for the first time some of the wicks are apt to be missing, and it must be arranged so that the oil will move through at the proper place, wicking or no wicking.

A. L. DeLeeuw.[5] There are many cases in which a relatively small quantity of product can be produced on an automatic machine provided the tool equipment is not expensive and the set-up time not long, and as there are in existence at present many automatic machines in which both these requirements are met, every one should carefully consider whether one of the present types or perhaps a new type of machine would not be suitable for his work, notwithstanding the fact that he may not produce in large quantities.

Every shop man looks with a great deal of interest to see if a shaft or a gear or any part can be quickly removed in case repairs should be necessary. I do not wish to suggest that this is not an important consideration, but it is not all-important, and it is not as important as some other things. If designers can improve the mechanism but at the cost of some little delay in removing the part if necessary, they should not compromise. They should make the machine better and even let the man who has to do the repairing sweat a little bit. If the designer can make the machine so as to save one second on a minute's operation, then in the course of a year the total time saved is 40 hours, a long time to allow for the removal of a shaft and hence a considerable net saving.

In many cases a station machine might be used to good advantage, especially where quantities are fairly large though not necessarily extraordinarily large. Certain machines can be built so that it would be possible to take various heads off and put other heads on so as to make the machine capable of working on a variety of pieces. Such machines have been built, and many more could be built if again there were not that prejudice that seems to come up automatically in people's minds that enormously large quantities of pieces are required before such a machine becomes profitable. That, I find, is not the case. It is sometimes the case but not always. Again, here, careful consideration is necessary.

Our machines have been built from old practice, and old practice means a shop in which a machine had sometimes to drill a small piece, next a long piece, and then a wide piece, sometimes a high one and sometimes a low one. The machine was built so that it could take care of all these pieces, and in building a machine this way it became clumsy, expensive, and not very fit for any one of the operations. At the present time most of our manufacturing is not carried on that way. Most of it is done by single operations and machinery set for a certain operation. In 1900 and for a few years thereafter, everybody was impressed with the necessity of having a quick-change-gear arrangement on the lathe and milling machine. This is quite correct if a great variety of work must be done on a machine, but if a machine is at

[5] Consulting Engineer, New York, N. Y. Mem. A.S.M.E.

work for a few days and sometimes months and sometimes year after year on the same operation or the same kind of operation, there is no longer any benefit in having an expensive attachment to it for no other purpose than to save a few seconds in changing the feed or speed. In such cases the ordinary change gears or pick-up gears are all that is required. If a machine is at work three or four days at a stretch on one operation and it takes, let us say, three minutes to remove a pair of change gears and put another one on, the percentage of saving that can be made by a quick-change-gear arrangement does not pay.

S. Einstein.[6] The author mentions a number of improvements and suggestions which have been offered in the past to machine-tool builders, such as roller bearings, enclosed motors, and better lubrication. The experience of most machine-tool builders is that whenever improvements are made, it is hard to get users of the tools to accept them. When Mr. DeLeeuw introduced in 1908 milling cutters with teeth correctly spaced there was a considerable argument about the design tending to prove that these cutters were not desirable for a number of reasons. Today these cutters are standard. So it is with the improvements which the author mentions, even roller bearings and ball bearings. It takes an uphill fight all the way to make users of machine tools see their advantages.

Another point brought out by the author is that the needs of industries such as his for small machines are not being cared for. This, I think, is true only to a certain extent. Take, for example, the centerless grinder. When we started out with the centerless grinder considerable pressure was put on us to make it much smaller than the small size we are building now. It was argued that here was a machine, weighing 4000 to 5000 lb. and of correspondingly large proportions, designed for small pieces, say, $^1/_{16}$ or $^1/_{32}$ in diameter. If the requirements of such a machine are analyzed, it will be found that a heavy machine is essential.

Neatness of appearance is naturally very desirable, but here again many problems are put to the machine-tool builder. If all the mechanism is put inside the machine, certain dimensions will become larger and make the machine heavier.

P. E. Bliss.[7] If I understand the author rightly, he says that users of machine tools are paying for and should receive the benefits of more development work. It is a fair question whether they are paying for it, although they may think they are paying for it. Let me illustrate what I have in mind. Recently the National Machine Tool Builders Association made an investigation of some thirty of its larger members making a variety of products, none of whom did less than a million dollars' worth of business a year for five successive years. More than half of the business carried on by them was done at a profit of 10 per cent or less, and only a part of the remainder of the business was done at a profit that reached 14 per cent. That profit when related to the usable items of investment in their business, as to the first section I quoted, was less than 5 per cent return, and as to the other section, probably not in excess of 7 or $7^1/_2$ per cent return. The builders of machine tools are not satisfied with the amount of development work they have been able to carry on, but where the return is so meager the amount of money available for such purposes of necessity must be limited. I think it can be shown that in proportion to the volume of business which the industry does and the net return, the amount of development work carried on is in excess of the amount carried on by any similar national industry.

[6] Chief Designer, Cincinnati Milling Machine Co., Cincinnati, Ohio. Mem. A.S.M.E.

[7] President, Warner & Swasey Co., Cleveland, Ohio. Assoc. A.S.M.E.

O. W. Boston.[8] I wish to raise the question as to whether or not individual lighting arrangements, incorporated in the machine, are desirable in all cases. It seems to me that when individual lights are placed on machines the machinery becomes very complicated and the lights soon get out of order. I wonder if an adequate lighting system, lighting the room as a whole, is not more efficient in the long run.

The author takes up very seriously the question of guards. I am not at all conversant with the various state laws on guards, but it is my understanding that the machine-tool builders are up against a rather serious problem when they equip their machines with guards because a guard which is satisfactory to the laws of one state might not be satisfactory to the laws of another state. I am not sure that The American Society of Mechanical Engineers is doing anything by way of standardizing those practices. It might be desirable to instigate some action along that line.

L. D. Burlingame.[9] I was brought up in a factory where a standard type of machine was established. Because of carrying in stock, we could deliver it to the customer on receipt of a telegram or at a day's notice, and orders were refused which were not for that standard type. Soon the pressure became such that it was necessary to change the product to some extent to meet the needs of customers, and it gradually developed that the users impressed the manufacturer with the thought that the latter was better qualified to perform the service of equipping his machine with such modifications.

One such step is illustrated by the screw machines which were developed to be entirely automatic. Then came the turret forming and the threading machines; thus three kinds were developed. Each of these was built with or without motor, making six kinds, and then each of these was adapted for high and for regular speeds, making 12 kinds. Another variation makes 24, and another 48, until the whole thing becomes impossible. The solution has been partly found in the unit system, by which quick modifications can be made on machines carried in stock.

I believe there is closer and closer cooperation between the user and the manufacturer, but it is still somewhat of an open question as to where the cost should be borne. The cost of service is not one that it seems should be paid by the man who wants the standard equipment only. There are those who want special-purpose machines. The cost, I think, should be borne by the one receiving the service.

W. L. Millar.[10] In the early days it was recommended by the motor manufacturer that the motor be mounted so as to be up out of the dirt. On account of the fact that customers so many times specified that they must have a certain make of motor it was practically impossible for the manufacturer to incorporate the motor in the base of the machine. Therefore it seems necessary to allow the manufacturer greater leeway in selecting the make of the motor, or the principal dimensions of various makes of motors should be standardized.

E. F. DuBrul.[11] There is a growing demand among machine-tool users for standardization. Standardization of the things that affect the user are very properly, to my mind, the subject of the user's demand.

[8] Professor of Shop Practice and Director Engrg. Shops, Univ. of Mich., Ann Arbor, Mich. Mem. A.S.M.E.

[9] Indus. Supt. and Pat. Expert, Brown & Sharpe Mfg. Co., Providence, R. I. Mem. A.S.M.E.

[10] Mechanical Engineer, Gisholt Machine Co., Madison, Wis. Mem. A.S.M.E.

[11] General Manager, National Machine Tool Builders' Association, Cincinnati, Ohio. Assoc. A.S.M.E.

This year the standardization of milling-machine arbors was a progressive step which will eventually show good results for manufacturers as well as the users. The principle can be extended to many different machine-tool elements.

The designer of any mechanism has to be infected, so to speak, with the production idea, if he is going to design production machinery such as the author has shown, and it seems to me that the machine-tool designer is not exposed to this infection at his own drawing board. If he is going to catch this infection, he must go where production is going on. The production atmosphere accounts for the development and the necessity of a staff of the size the author has mentioned, at the Western Electric Company. If it is a good thing for the machine-tool designer to get the production infection, I suggest that he be sent out where it is likely to attack him.

I have often thought as Mr. DeLeeuw has said, that we must be adding unnecessary complication to machine tools. I wonder why every lathe has to be built with a screw-cutting apparatus when most lathes probably are not used for cutting screws. I wonder if all the combinations of feeds and speeds are needed in radial drills—are really used in service. Perhaps the radial drill is enough of a general-purpose tool to require all of these combinations, but do the users of the radial drills see to it that the men operating their machines are using the facilities that are provided for them? The users like to have these things. The manufacturer who gives the most feeds and speeds has a marked advantage. It certainly adds to the cost of producing the regular line of machines to incorporate such complications, but do the users really use them after they have bought them?

Last September, Mr. Blanchard, of the Bullard Machine Tool Company, presented a paper before the Society of Automotive Engineers in which he discussed the method of "simultation." The machines I saw were a very fine example of simultation. They were for machining the carbon electrodes used in electric furnaces. An electrode is pushed into the machine at one side. Jaws on a big drum take hold of it at the bottom and carry it to the first station. Here the two ends of the electrode are drilled. The drills are withdrawn, and then the drum carries the electrode to the second station. As it moves around it passes between two disk grinders—stock machines furnished by another builder—mounted on the large machine, and by which the ends are faced. It stops at the second station at which two planetary milling machines furnished by a third builder are mounted bodily on the machine and by which internal threads are milled in the electrode. Then the drum carries the finished electrode to the bottom where the new one is pushed in, and pushes out the finished piece on the other.

It cost quite a bit of money to design and build this machine; it is the only one of its size and kind. Its existence is due to the ability of some designer to "simultate" these operations that makes it economical. This principle of simultation has been carried out in many station machines. But here is a case of "simultating" three different kinds of operations, two of them involving two complete machine-tool units that are simply attached as complete elements in this large construction.

The Author. There is no doubt, as stated by Mr. Spence, but that individual motor drives cost somewhat more than countershaft belt drives, but when the standardization of motors becomes a reality the difference in cost will greatly diminish. As I see the future, the smaller concerns who buy used machinery, as a great many of them do today, will eventually be buying the second-hand motor-driven machines, and in that way the entire manufacturing field will in time be supplied with the individual-motor-driven equipment. Then there will be no more need of discussing the relative merits of the two systems. The individual-motor drive is an element of progress and its universal adoption eventually is certain.

In regard to the placement of motors referred to by Mr. Hoagland, we prefer not to mount them on the tops of machines though we are not arbitrary about matters of this kind. We put the motor where it can be used to the best advantage.

Mr. DeLeeuw made a very good point when he said that accessibility is not the most important consideration. In buying or designing new machinery we expect the maximum of accessibility. I agree with Mr. DeLeeuw, however, that the importance of accessibility is sometimes overestimated.

In regard to the station type of machine, it is without question coming into more use. We have bought several and also are developing some of our own.

Mr. Einstein and Mr. Bliss spoke of the difficulties of machine-tool builders. We realize that they have their problems and that they are real problems. They are being met very capably by some of the builders. The outstanding builders who maintain efficient engineering and development organizations are not complaining much.

Relative to Professor Boston's question of the advantage of individual lighting, it is not our practice to put individual lights on machines regardless of the kind of a machine or the kind of operation; we use the general illuminating system as much as we can. We have very good lighting in our plant, but we recognize that there are many machines on which it is necessary to have individual lights so that the operators can see what they are doing without effort, and we do not hesitate to install them if it is necessary.

With regard to the laws of different states governing the guarding of machinery which conflict in many respects, these do not present any problem so far as we are concerned, for the reason that we endeavor to thoroughly protect our operators regardless of and often beyond the legal requirements. We have a plant in Illinois and another in New Jersey, and although the laws of the latter are more stringent than those of Illinois, our methods of guarding are the same in both plants and are more thorough in many cases than they need be if we followed the actual wording of the law instead of the spirit of it. We will not permit a machine to be used if it presents a noticeable hazard.

Mr. DuBrul has brought out the fact that machine-tool builders design their machines so that they are adjustable over a wide range. I have often heard salesmen use this as a sales argument. We do not care to pay an increased price for adjustments to cover a wide range of work when only a part of the range will ever be utilized.

I agree fully with Mr. DuBrul that machine designers should have an opportunity to study the economics of manufacturing. They know practically nothing about it. We solve the problem at the Western Electric Company by having two men on the job. One is an engineer who is capable of making a detailed economic study of the problem involved, and the other is a designer who has the engineering ability to lay out on paper the machine to meet the operating requirements, and the two work hand in hand. Designers should be encouraged to learn more about the economic factors involved in the designing and building of machinery.

# Symposium on Shop-Equipment Maintenance

*The first four papers composing the following Symposium describe the organization of the departments in whose charge this feature of the manufacturing problem is placed by four great American industrial concerns. The duties and responsibilities of the personnel of these departments are set forth, their relations with the production and other departments of the shops in question are described, the value of the records of maintenance expense is pointed out, and the methods of inspection to determine the need of repairs are explained in detail. The first paper deals with the methods used by the Westinghouse Electric & Mfg. Co., at East Pittsburgh, Pa., the second with those adopted by the General Electric Company at Schenectady, N. Y., the third, the organization at the National Cash Register Company's plant at Dayton, Ohio, and the fourth, the manner in which the problem is dealt with by the Hess-Bright Mfg. Co., at Philadelphia, Pa.*

*The fifth paper of the Symposium is more directly related to the fundamental economics of the question of plant maintenance. After defining plant maintenance as he understands it, the author lists twelve items which he later discusses in detail. He attacks the problem from the point of view of accounting practice in the distribution of maintenance expense and its effect upon invested capital, and after laying down some general principles, proceeds to apply the principles to the study of the twelve items previously enumerated, showing how the expense involved in each should be distributed. Leaving the economic aspects of the question, the author next sets up a personnel organization and physical layout to handle the problem of general plant maintenance. This is followed by some observations and warnings about the handling of repair orders. Finally, in a summary, the author returns to the economic phases of his subject and shows by an example how the proper accounting of expense will affect the return on the investment.*

## Plant Maintenance[1]

By GEO. H. ASHMAN,[2] SCHENECTADY, N. Y.

PLANT maintenance must be considered as a function distinct and separate from those pertaining to regular production work. It is supervised and carried out by an organization whose duties should have no connection with manufacturing. This department may be divided into three general branches; civil, mechanical, and electrical engineering. The first of these has charge of buildings; the second, of the machinery and tools; and the third, of power. While various plants will differ in regard to further subdivisions of this work, for purpose of discussion the following will be considered as best for keeping the executive in touch with the maintenance work in general, particularly in the matter of costs:

Buildings
Machinery
Electric apparatus
Ovens and furnaces
Dies
Patterns
Miscellaneous equipment
General plant facilities
Power, heat, and light
Safety devices.

### Buildings

The work of the buildings division should be divided into:

Care of buildings, including heating and ventilating
Sewers and underground conduits
Crane runways
Cranes; jib, traveling, gantry (exclusive of electrical equipment)
Elevators (exclusive of motors or control)
Roads and pavements.

A superintendent of grounds and buildings would be in charge of this work, and he would have on his staff a designing engineer, a civil engineer, a general foreman of construction, and foremen of carpenters, masons, structural-steel workers, and roofers.

The department is responsible for the safety and condition of walls, roofs, steelwork, stacks, stairways, and the safe load per square foot of all floors, for the cleaning of windows, and for all painting. Besides this a continuous inspection is made of crane runways and cranes, and of freight and passenger elevators.

### Machinery

The largest and most important division is that of machine tools and appliances, a number of interests centering here, such as the selection and purchase of new tools and their installation; the attaching of motors, control, and wiring; the repair, discarding, and scrapping of old machines; and the purchase of small tools and machine attachments.

The general superintendent of the plant has entire charge of this important phase of the work. The superintendent of a department asking for a new tool makes request on a special form giving a general description of the tool required; special features, if any; nature of work to be performed, with specific details; reasons for making request, whether new work, increased production, or replacement of a worn or obsolete machine. The saving expected in cost of production from this purchase is noted on this request.

Should the request be considered favorably by the general superintendent, bids are obtained by the purchasing department, through whose hands all correspondence passes, from manufacturers building the type of tool required. From these quotations and comments on them from the interested department, the general superintendent selects the machine. After the authorization to purchase has been obtained from the manufacturing committee, the machine is formally bought through the purchasing department.

Requisition for the necessary electrical equipment to operate tool is then made. This equipment is selected and designated by the electrical superintendent.

Foundations are built complete by the grounds and buildings department, and the machine is set in position by the millwrights—each a separate department having no connection with the organization of the shop in which the tool is installed.

The motor and control are next installed and the machine is wired by a special department controlled by the electrical superintendent. Before the machine may be operated for

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[1] Presented before the Metropolitan Section, New York, N. Y., Mar. 28, 1927.

[2] General Electric Co.

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production, it must be inspected and approved by a representative of the safety committee for gear guards and safety devices.

The machine is given a catalog number by which it is identified throughout its life; this number is not reissued when the tool is scrapped or otherwise disposed of, but remains as a perpetual record to identify it.

A separate account, kept in card-index form, is opened for each tool as it is received and installed. Besides accounting information there is given a general description, the capacity and purpose of the tool, feeds, speeds, maximum and minimum travel of essential working parts, and all special fixtures or attachments. The price of the bare machine appears as a separate item, all attachments, special fixtures, motors and control, etc. having their prices entered as extras. On the face of the card, besides the above information, is given the catalog number of the tool, date of purchase, name of manufacturer, and selling agent, if any, and its location in the plant. On the reverse side is noted all repairs or alterations made, giving date, nature of repairs, and cost. This information is of value in determining whether there is inherent weakness in the design of the machine, shown by the breaking of the same part several times. If the tool is not suitable for the work that it is performing, frequent repairs will be necessary. The second also indicates the extent of the abuse or the lack of proper care which the machine receives.

Every year a new depreciated value is entered on the record card, the rate of depreciation being governed by the class of tool (whether lathe, planer, drill press, punch, hydraulic press, etc.); by size (for example, small lathes are given a higher rate of depreciation than large ones); by location in the shop (toolroom lathes having a lower depreciation rate than production lathes, etc.); by obsolescence (change of methods of manufacture being more likely to affect certain classes of special tools than others).

The foreman of the department in which the machine is installed is responsible for its mechanical operation and upkeep, and for the instruction of the operator in its use. Particular attention is paid to lubrication; an automatic oiling system operating from a central tank on each tool is installed whereever possible, eliminating individual oil cups. Instructions are issued indicating the proper grade of lubricant to be used for each particular service, and attention is called to parts requiring grease lubrication under pressure.

The care of belting, renewal, proper tension, etc. is attended to by an expert gang in each department.

Repairs are undertaken at the direction of the foreman with the approval of the superintendent or general foreman of the department where the machine is located. Minor repairs or emergency breakdowns are taken care of by the tool-repair gang of the department. Major repairs are made by a separate department, equipped for this class of work. Repairs of this nature are only undertaken after a close estimate of the cost shows a good margin below the cost of a new tool. The depreciated value of the tool and obsolescence are factors in the decision for or against repairs.

Chucks, taper attachments, relieving attachments, collets, etc. and all replacements are handled by a central and separate small-tool department. Cold saws, milling cutters, grinding wheels, drills, reamers, arbors, etc. and all hand tools—hammers, wrenches, files—are also handled by this department. Data concerning their life and fitness are kept, and future requirements filled from those showing the best results.

All cutting tools for lathes, planers, millers, etc. are supplied by the small-tool department, which selects the proper tool steel, unless this is specifically designated on the requisition; it forges or constructs the cutters and grinds them for service, subsequent grinding or sharpening being done by the toolroom of the section operating the machine. The use of specially shaped cutting tools is discouraged. Facsimiles of standardized tools are exhibited in conspicuous places, each sample being uniformly numbered, and the operators make request for new tools in accordance with these numbers, no other shapes being furnished without very sufficient reasons.

All tools, lathe, planer, milling cutters, broaches, and drills are ground to exact contours by machine, in the various toolrooms, and other than rubbing up or dressing the cutting edges, workmen are cautioned against further grinding or shaping their tools by hand.

The small-tool department is also responsible for gages and measuring devices of all descriptions. This department not only furnishes the gage called for (being responsible for its accuracy), but also by weekly inspection checks each gage either by direct remeasurement or by comparison with master gages.

### Department of Power, Heat, and Light

Electrical apparatus, ovens, and furnaces come under the department of power, heat, and light. This department is divided into two sections, one electrical, the other mechanical, with the heads of these separate divisions reporting to one superintendent who is held responsible for the operation of both. The electrical division has charge of the selection, installation, and upkeep of all motors, generators, and controlling devices, and of all wiring, including transformers, throughout the plant. It will make all running and emergency repairs, replacing bearings, removing and replacing armatures and rotors, defective coils, contactors, fingers, and solenoids in controllers, brakes, etc. All lamps and fixtures, their installation and upkeep both in office buildings and shops, are under the care of this division.

The care and operation of the electrical features of the shop electric plant are under the direction of this division, and it is responsible for furnishing all current to the plant.

The steam engineer in charge of the mechanical features has direct control of all power plants (exclusive of electrical appliances).

The selection, location, and installation of boilers, stokers, feedwater heaters, pumps, blowers, exhausters, compressors, steam engines, and turbines and all coal-handling machinery and coal storage are directly under him. He is responsible for all alterations and repairs made to this equipment.

All piping throughout the plant—steam, water, air, and gas—is installed and kept up by him. He also is in charge of the design, installation, and repairs of furnaces, ovens, and fuel-oil systems. Heating systems are also under his jurisdiction.

### Die, Pattern, and Jig Work

One of the most important operations in a large plant, and one in which, next to machine tools, the greatest expenditure is made, is die, jig, and pattern work. Because of the nature of this branch of construction, it is centralized in separate departments, supervised by men who have specialized in this particular class of work and are familiar with the operation of dies for drawing, forming, and punching the various metals; molds suited to the several compounds molded; their proper proportioning and strength and the correct steel to use for the block, together with the best heat treatment to use. The storage of dies is an important consideration. A fireproof, heated building centrally located, is provided having crane facilities for handling the heaviest dies. All dies are inspected and put in first-class condition before being returned to this building.

### Transportation

Another department having a marked influence on cost of

plant maintenance is that of transportation: receiving material, movement of material and semi-finished parts from one department to another, movement of material within shop buildings, and shipping the finished product. Material is necessarily received and products shipped in broad-gage cars, therefore a system of standard-gage tracks is needed not only to the main receiving and shipping departments but to each shop, to save the labor of transfer of the bulkier and heavier material to the shop transportation lines.

For movement of material between shops a narrow-gage railroad seems to be the best solution of the problem, rather than a gas or electric tractor with trailers. Larger and heavier loads can be handled by one tractor and cars on a track, and cars be shunted into buildings, not pulled, conserving aisle space.

For transporting smaller loads of lighter material both between departments and from floor to floor in buildings, the electric truck, with and without lifting and tiering devices, and the tractor and trailer is the most mobile and also the cheapest unit.

### Safety Devices

Safety is handled by a separate department whose duty it is to see that the state industrial code is complied with in all cases, and that regular inspections are made of cranes, crane slings, elevators, elevator shafts, steam boilers, etc.

All new and relocated machine tools must be appraised by this department as to safety appliances before they are regularly operated. In each shop safety committees are appointed from among the employees, and their duty is to make suggestions to the safety department covering accident prevention and safety regulations and appliances.

Fire-protection apparatus and fire prevention are under the care of a fire department, which makes daily inspections throughout the plant, covering fire hydrants, hose, sprinkler systems, water buckets and extinguishers. It is responsible for the installation of all fire-protection apparatus and appliances.

# Plant Maintenance and Return on Capital Investment

By W. H. CHAPMAN,[1] HARRISON, N. J.

THIS paper is intended to serve as an expression of the author's opinions upon the subject of general plant maintenance viewed from the standpoint of obtaining the greatest possible return for expenditures which may be considered as chargeable to maintenance items.

Each plant must, of course, be considered according to conditions which exist due to the nature of product manufactured, plant layout, organization, and its financial structure. The management must become thoroughly acquainted with its maintenance problems through careful analysis of the various phases and establish certain policies pertaining to the accomplishment of the physical work, as well as the proper distribution of expenditures.

Efficient organization of personnel involved, with clean-cut placing of responsibility, is paramount. Equally important is a clear understanding of accounting problems. Without an accurate picture of the effect of maintenance upon his financial structure, a manager cannot hope for efficient maintenance control.

### Definition of Plant Maintenance

Plant maintenance, as treated in this paper, is defined as money expended over a given period of time for the sole purpose of maintaining a manufacturing physical structure at a point of operating efficiency that will permit the operating personnel to meet existing set standards of production performance.

This definition assumes that standardization of equipment and labor performance exists, consistent with expected rates of production and degrees of precision in manufacture, so that factory costs of manufactured articles have been accurately determined.

Any changes in equipment, instituted for the purpose of changing existing standards (whether due to changes in product design or methods of manufacture), are not classed as maintenance items. These are development items involving capital expenditures and are brought about for reasons of sales policy, quality of product, or an opportunity to increase return upon investment by cheaper methods of manufacture.

### General-Maintenance Items

General-maintenance items include the maintenance of

1 Buildings and grounds
2 Power-supply equipment
3 Machine-tool equipment
4 Processing equipment
5 Tools (perishable and permanent)
6 Materials-handling and storage equipment
7 Power transmission
8 Furniture and fixtures (office equipment)
9 Laboratory and experimental development equipment
10 Expense stores maintenance supplies
11 Heat-treating equipment
12 Fire-prevention and safety equipment.

Each plant has maintenance problems peculiar to itself, but for the average concern engaged in fabricating the more common engineering materials, the above classification is suggested.

### Accounting Practice in Distribution of Maintenance Expense and Effect upon Invested Capital

The gage of success of a business enterprise may be expressed in terms of percentage of net return upon invested capital. The amount of invested capital will fluctuate, and the most important problem faced by management is the control of the organization so as to obtain a satisfactory net return under the varying business conditions which may occur. Viewed broadly, it is important to regard expenditures from the standpoint of their effect upon this return on investment, in order that policies laid down to the responsible working personnel may be constructively interpreted and controlled.

It is important to recognize the effect of accounting distribution of maintenance items upon net return. In most lines of business there is a considerable variety of product in process in the factory at all times. It is usually true that parts which are being made in large quantities, and therefore permit the development of the cheapest manufacturing costs, are also subjected to the greatest competition and, therefore, show the smallest margin of profit, per piece, in a competitive market. Lines which are more or less special, or entail proportionately large manufacturing expenditures to produce, may in themselves create excessive maintenance burden. In the distribution of this burden against the various manufacturing departments, it may be readily seen that policy must be determined through the effect upon selling prices of various items, and the knowledge of the effect of these prices upon the profits of the business as a whole. Factory costs are usually the basis of arriving at selling prices. A very large percentage of the item of factory cost is made up of burden items, of which maintenance items

[1] Assoc-Mem. A.S.M.E.

are usually of considerable magnitude. In allocating burden centers for distributing expense items, it is important to consider not only the nature of equipment and operations involved, but also the variety of size and shape of product reflected in the relative amount of physical effort and expense required for each one of the various items. It may be desirable to create separate burden centers in the same manufacturing department, to enable differentiation between popular sizes and more or less special sizes and to prevent over-absorption of burden by the popular sizes which are subjected to the closest competition in the selling field.

It may also develop that certain sizes of product require special methods or equipment peculiar to themselves, which create costs not logically chargeable to the remainder of the product. Close study of such a situation will probably indicate the advisability of creating separate burden centers for the purpose of collecting created expense items and charging them against the product responsible; thereby insuring a more accurate basis for determining a logical selling price, and saving the more popular product items from burden inflation.

On the other hand, a concern may be fortunate enough to obtain a market for a large volume of sales involving an item which it can manufacture to extreme advantage, and which may then serve to absorb burden and permit reductions in selling prices on other items which otherwise would be handicapped in the competitive field. The successful manager will have his selling data and factory cost data well enough in hand to be able to set his policies for the guidance of his accounting department so that burden may be distributed logically to produce the desired effect.

### Buildings and Grounds

The expense of maintaining buildings and grounds includes such items as painting, roofing, repairs to masonry, floors, windows, fences, street pavements, curbing, sidewalks, lawns and gardens, trackage, platforms, etc. Lighting, plumbing, and heat equipment not involved in manufacturing processing, are also included from the accounting standpoint under buildings, to be distributed over the various burden centers.

The distribution of the above items should logically be upon the basis of floor space and the following method is suggested: Post all charges for the period covered (say, one month) and obtain the total maintenance expense represented by labor, supervision, material, etc. Obtain the percentage of floor space occupied by each burden center relative to the total floor space occupied by direct manufacturing activities. Multiply the total maintenance expense by each percentage and charge its proper proportion against each burden center. Each burden center is considered a tenant in the building which must be supported by the sum total of the producing burden centers, and expenses of building maintenance are equitably distributed upon the basis of space occupied. Non-productive departments are absorbed as a total, and distributed among the "paying tenants."

### Power-Supply Equipment

Power-supply equipment refers to power house and the general transmission of power not properly contained within any particular producing department, and comprises electrical, pipe-line, and power-generating equipment. It also includes materials-handling and storage equipment used for the purpose of fuel supply, ashes, etc. It is suggested that total maintenance charges of this class be distributed upon the basis of the percentage of total power used by each producing burden center. This is determined by electric, gas, steam, and water meters in each burden center.

### Machine-Tool Equipment

Maintenance of manufacturing machine-tool equipment accrues against the particular burden center involved, depending upon the amount of service expense required, and becomes a direct-expense charge for each burden center. Similar equipment located in service departments, such as tool rooms, machine shops, etc. is maintained as a part of the regular service expense, which is prorated over the producing burden centers in proportion to service work rendered. It may be considered as a part of the burden of service departments whose total expenses become absorbed through prorating among producing burden centers on the standard labor-hour basis.

### Processing Equipment

Processing equipment refers to cleaning, plating, painting, oiling, and similar equipment. Maintenance of these items should be handled, and expense distributed, in the same manner as outlined for machine-tool equipment. Each burden center is directly charged for service rendered, including repairs to accessory equipment, such as pipe lines, pyrometers, storage and pumping systems, etc. which have been definitely allocated to individual burden centers under the plant layout.

### Perishable and Permanent Tools

Perishable and permanent tools are chargeable directly to the burden centers in which they are consumed or used. Perishable tools are both repaired and replaced at frequent intervals and may be charged to maintenance accounts unless replaced due to changes in design or methods of manufacture. Permanent tools are maintained and charged directly, as repairs are made, to maintenance accounts, except when replaced due to obsolescence. These items usually represent heavy expenditures and require close supervision and control. The record of their performance as indicated by a system of detailed repair-order cards is of extreme importance in the appraisal of their value by interested executives, and also in forecasting probable requirements for the control of a large part of expense stores investment. The keeping of such records will be more fully discussed in a following paragraph.

### Materials-Handling and Storage Equipment

Railway equipment, automobiles, motor trucks, conveyors, cranes, inside trucks, "tote" pans and platforms, bins, scales, stock racks, etc. are included. Due to the interdepartmental transfer aspect of a great many of these items, direct-burden-center charges appear impracticable, and all repairs over a given period are lumped, and distributed upon the basis of the ratio of actual productive-labor man-hours occurring for the period in a particular burden center, to the total productive-labor man-hours for all of the producing burden centers during the same period.

### Power-Transmission Equipment

Power-transmission equipment refers to motors, electric lines, fuses, switches, starters, etc., pipe lines for water, gas, oil, steam; etc. leading from sources outside of the burden centers served, belts, pulleys, clutches, shafting, hangers and bearings, and similar miscellaneous equipment. All repairs or replacements of such equipment (except due to change of design or plant rearrangement) are chargeable directly to the burden center served. Maintenance of this nature is always a large item, and here again the value of accurate repair-order records will be found of great value to the organization. The determination of relative economy of performance of belts, hanger bearings,

clutches, motors, etc. will far more than repay the cost of obtaining the data.

### Furniture and Fixtures and Office Equipment

When located in a producing burden center, maintenance of furniture and fixtures is charged direct. For non-productive departments, total maintenance is lumped, and distributed against the burden centers on the standard labor man-hour basis. Office equipment refers only to that chargeable to manufacturing administration and does not include sales.

### Laboratory and Experimental-Development Equipment

Repairs of all kinds to laboratory and experimental-development equipment are lumped and distributed over producing burden centers as a part of the general plant overhead, upon the basis of labor man-hour percentage for each burden center.

### Expense Stores Maintenance Material

Certain items carried in expense stores are drawn out as needed and used in repair and maintenance work. When this occurs, the value of the material requisitioned and delivered is indicated upon the repair order and is thereby transferred from capital investment to works expense as explained in a following paragraph.

### Heat-Treating Equipment

It is suggested that these items be accounted for in the same manner as processing equipment.

### Fire-Prevention and Safety Equipment

Fire-prevention and safety-equipment expenses are distributed upon the floor space or "tenant" basis over the producing burden centers, as was suggested for "buildings and grounds" items. This refers only to repairs or replacements for the purpose of maintaining this equipment in first-class operating condition. Recharging of chemical extinguishers, etc. would fall under this class of maintenance.

The above indicates in a general way the suggestions offered for controlling the expense of handling maintenance work so that the costs involved may be readily studied and be properly posted by the accounting department in making up cost data for determining a proper basis for calculating selling prices. Where part of the product does not make use of certain of the burden centers, it is relieved of the proportionate burden which might otherwise accrue against it under other methods of cost distribution. A chance for flexibility in determination of factory costs of individual items presents itself without the danger of unknown or unexpected losses occurring due to unabsorbed burden created by maintenance items. The usual magnitude of these items makes for extreme importance in their intelligent control.

### Personnel Organization and Physical Layout to Handle General Plant Maintenance

The magnitude and ramifications of the personnel organization required to handle general maintenance work depend upon the size of the plant, the nature of the manufacturing processes, and the degree of precision to which machining operations are held. For large corporations having plants in several locations this organization may assume considerable proportions. For individual plants it is often remarkable how few people are required when properly organized and equipped to handle this sort of work. Maintenance work requires the services of skilled workers who are specialists in each of a variety of trades. Mechanics, tool makers, millwrights, riggers, electricians, plumbers, pipe fitters, tinsmiths, welders, blacksmiths, painters, carpenters, and laborers are all necessary. Many of these men are occupied at their trades within the plant on other than maintenance work for a great deal of the time, and for most plants a distinct maintenance department, fully manned, would not be economical. The handling of maintenance work under these circumstances is necessarily divided up among a number of departments which are not primarily created for maintenance work. The machine shop and tool rooms will have, however, a considerable part of their time taken up due to maintenance requirements in conjunction with the usual work done on new equipment, alterations, experimental tools, product development, etc.

Executives responsible for maintenance work in the average plant should be chosen so that their part of maintenance is logically in line with their other duties. The following layout is suggested as suitable in the average case.

1 Plant Engineer.

Maintenance duties cover the following items:

- Buildings and grounds
- Power-supply equipment
- Processing equipment
- Materials-handling and storage equipment
- Power-transmission equipment.

He will supervise:

- Safety engineering
- Watchmen
- Fire department
- Power house (electric, steam, gas, oil, and water)
- Electricians
- Plumbers and pipe fitters
- Millwrights, riggers, and belt men
- Outside transportation and storage systems
- Tinsmiths
- Masons
- General laborers.

When the services of mechanics, carpenters, welders, etc. are required in conjunction with the above, they are requisitioned from their respective departments, and their part of the job is supervised by their regular foremen to the satisfaction of the plant engineer, who assumes final responsibility.

2 Master Mechanic or Manufacturing-Equipment Engineer.

Maintenance duties cover the following items:

- Manufacturing machine-tool equipment
- Perishable and permanent tool equipment
- Furniture and fixtures
- Laboratory and experimental development equipment.

He will supervise:

- Machine shops and tool rooms
- Equipment-development work
- Machine and tool design
- Pattern and carpenter shop
- Standard methods and rate setting.

Each of the above individuals reports to the works manager and is responsible to him for proper maintenance service to all departments. Maintenance work is therefore handled without the creation of special executives for the purpose, but with responsibility clearly defined. Furthermore, no production executives are troubled with having to supervise maintenance but can look for assistance from those who are logically in a position to give them the best possible service in maintaining an efficient production layout.

It is felt that the above suggestions will prove of value to

management in the control of maintenance work for the following reasons:

1 Clear-cut responsibility for this work, assigned to permit minimum personnel requirements.

2 Accurate cost data available to serve as a guide to control expensive items of factory costs and permitting a flexibility of cost distribution to meet indicated sales resistance in a competitive field.

3 A clear indication of effects of factory costs upon return on investment, and data from which close forecasting of future costs is possible; in other words, a gage of the probable health of the business.

4 Maintenance experience is gained by those executives who also serve to determine manufacturing methods and equipment. This experience is therefore of utmost value in aiding arrival at the proper choice of these items and thereby obtaining the most suitable manufacturing layouts.

It is realized that in many plants peculiar conditions are present which will require a different treatment of maintenance problems. However, it is hoped that by bringing the foregoing ideas up for thought and discussion, some benefits may accrue to those interested in this phase of plant management, and that executives will realize that the importance of maintenance work is more far-reaching than is ordinarily appreciated.

### Handling of Repair Orders

It is important that the organization be thoroughly schooled in the proper classification of maintenance work to prevent inflation of maintenance expense. It is very common to find expenses charged to maintenance accounts which in reality are created by activities of a development nature (or else so-called "Government jobs") and which, from an accounting standpoint, should be set up as capital items and not as increases to works expense.

No system of authorizing and recording maintenance activities can be devised to overcome the misdeeds of persons who knowingly permit wrongful charging of time and materials. Only by intelligent appreciation of the detrimental effect of such practices can they be reduced to a minimum. Any responsible foreman must be as thoroughly alive to this fact as to the importance of the proper handling of his major production problems.

It is the author's opinion that the very foundation of successful maintenance-expense control lies in the success of the management in gaining full coöperation of production executives along these lines.

The control of repair orders in service departments must be handled with extreme care to prevent abuses and excesses of various sorts which are apt to be charged to orders for maintenance work. It is the author's opinion that it pays to expend sufficient clerical effort upon this class of orders to insure the keeping of accurate records of the nature and extent of each job; also to disseminate the data collected to interested executives as an important means of checking unnecessary expenditures, and to check the performances of both operators and equipment. Many sore spots in equipment or in methods of operation are clearly indicated by such records. They serve as valuable indexes when replacement of equipment is under consideration. Standing repair orders of a general nature, which fail to record accurate data regarding maintenance expenditures, frequently serve to cover up numerous activities which would not otherwise be authorized and are of questionable advantage to the concern.

When materials are requisitioned from expense stores for maintenance purposes they represent a transfer (from an accounting standpoint) from invested capital, indicated by their purchase price, to an expenditure chargeable to works expense. In other words, invested capital is reduced by an amount which is entered as a charge deductible from profits or net return upon invested capital. A close control of inventories represented by such materials is essential in order to keep down investment upon which a satisfactory return must be made. Here again the data obtained from specific repair orders can serve an extremely useful purpose. By the use of suitably printed cards which are punched in designated spaces, the necessary data may be quickly indicated and the cards later sorted by machine so as to keep such records without excessive clerical cost. This system is commonly used in a variety of ways, and involves very little outlay to be put into satisfactory operation.

### Summary

In the foregoing paragraphs the author has attempted to point out policies which apply to the average case without going into details. Details must of necessity apply to more or less individual plant layouts. It is felt that an organization which thoroughly appreciates the need for regarding the manufacturing plant as a financial institution attempting to earn the greatest possible return upon its invested capital, will be capable of working out necessary details along the lines of the general policies indicated. It is the lack of knowledge of such policies which handicaps many otherwise efficient engineers and production men, and causes the introduction of personal ideas that are often sincerely believed to be helpful, but which may be detrimental to the main object of the plant as a whole.

Because of the custom of gaging the success of business enterprise in terms of percentage return per annum on invested capital, and regarding capital as money borrowed at a rate of 6 per cent per annum, the following example may be of some value in stressing the need for proper understanding in handling maintenance expense items.

Assume that a concern at the close of a year's business is capitalized at $1,000,000. Operating expenses have been $2,000,000, and net profits from sales have been $300,000. The year's business has then shown a 30 per cent return on the investment, or a 24 per cent return after deducting 6 per cent interest on the capital investment. If, during the year there have been alterations to machines which have improved operating conditions, and, say, $100,000 has been spent to accomplish this but charged against repair orders, then this $100,000 has been charged to works expense rather than to new capital, and net profits have suffered by this amount while invested capital has not increased.

If the expense had been properly accounted for, the firm would have borrowed working capital of an additional $100,000, making the following showing:

| | |
|---|---|
| Invested capital | $1,100,000 |
| Operating expenses | 1,900,000 |
| Net profits | 400,000 |

Return on investment, 36.36 per cent, or 30.36 per cent after deducting 6 per cent for interest on invested capital.

The above figures are not intended to be accurate but to serve only to indicate the nature of the problem which must be kept in mind by all concerned, so that the best possible showing may be obtained.

It is not intended to give the impression that it pays to inflate capital investment, as this should be kept to a minimum, especially through controlling inventories, but it will serve to show the care necessary so that the annual balance sheet may reflect the best possible condition from a financial standpoint and thereby best serve the interests of the stockholders.

# Maintenance of Shop Equipment

By J. R. Weaver,[4] East Pittsburgh, Pa.

At the main works of the Westinghouse Electric & Mfg. Co. at East Pittsburgh, Pa., there is a large amount of equipment which must be properly maintained. To do this arrangements have been made to keep it in working condition at all times instead of waiting until a machine breaks down or requires a complete overhauling. In this way manufacturing is carried on with very little interference and without the necessity of having duplicate equipment to take care of shutdowns due to repairs. The organization which is charged with equipment maintenance is described in this paper.

## Checking Up on the Machine Tool

Each department has a tool supervisor who reports directly to the superintendent of that department and indirectly to the superintendent of the equipment department. The tool supervisor is the mechanical man in the department in which he is located and is responsible in all respects for the tools and equipment over which he has jurisdiction. He must see to it that he obtains the right machine tools for the job and that the machines are properly tooled. He must see that the machine tools and fixtures are properly maintained. We have about fifteen tool supervisors in the East Pittsburgh works.

In addition to the tool supervisors we have a force of machine-tool demonstrators. There are about fifteen demonstrators in the East Pittsburgh works and they report to the superintendent of equipment. These men are specialists in that each is trained to cover just one kind of machine tool; one man is trained on grinders, another on milling machines, etc. These men are responsible for proper selection, maintenance, and operating conditions for their particular kind of machine tool throughout the entire shop. Twice a month the demonstrators inspect machine tools throughout the shop for cleanliness and need for repair. In this way it is possible, to a very great extent, to locate machines that are in need of repairs and to correct them before a serious breakdown occurs.

The foremen and assistant foremen of the various departments are naturally interested in keeping their machines in good repair at all times, and they also help to keep the tool supervisors and demonstrators informed as to the condition of the machine tools in their departments.

## A Special Repair Department

The methods of locating machine tools that are in need of repair have been pointed out. To make these repairs there is a repair department thoroughly equipped for repairing all kinds and sizes of machines that are used in the shop. This department is in charge of a superintendent who reports directly to the works manager. It is divided into several sections in order to facilitate the work that is to be done in it.

A machining section is provided in this repair department to take care of any machining that it may be necessary to do. A variety of machine tools makes this department largely self-sufficient, and only in case the work is very large is it necessary to send it out of this department. In such cases the work is done in the large-machining aisle.

The assembling section of the repair department is equipped so that, if necessary, a machine tool can be completely rebuilt. In this department special machine tools which cannot be bought in the open market are also built.

The field section is composed of a number of men scattered throughout the various production departments in the shop, who make minor repairs and attend to any trouble jobs that may develop. This has helped to a great extent in keeping the machine tools in operating condition, and only in cases of serious breakdown is it necessary for the field section to send the machine tool to the repair department.

## Cost Records

An accurate record is kept of the cost of repairs. This is done through a system which compels the repair man to report the time spent on the repair job. All machine tools are numbered, and the repair cost is recorded against the machine-tool number. A permanent record is kept of the cost of repairs to the machine tools. At the end of each month a report is sent to each superintendent in the shop giving him the cost of repairs to his equipment during the preceding month. This report shows whether the repair was made necessary by excessive wear, accident, or negligence. The superintendent can then investigate and correct whatever may have been responsible for the breakdown. By the use of this permanent record it is also easier to decide when a machine tool should be replaced due to the excessive cost of upkeep.

## Safety Devices

A safety-application department is also maintained by the repair department for the purpose of properly guarding all machine tools. Up to the present time this department has very thoroughly canvassed the shop and has applied guards to prevent accidents. All new equipment, as it is received, is checked by this department, and if it is not properly guarded the manufacturer is notified and a proper guard is applied before the machine is actually put into operation.

Through the efforts of this department in conjunction with the safety department it has been possible to reduce lost-time accidents from 140 per month in the year 1924 to 54 per month in the year 1926. In fact it is found that most accidents at the present time are not due to machine tools but to the carelessness of the workman in handling material. There are more accidents due to the accidental dropping of material than to improperly guarded machine tools.

There are very few breakdowns due to the dropping of a wrench or other material into the working mechanism of a machine tool. This has been prevented by proper guarding.

## Replacement

Every three months a survey is made of the shop for the purpose of replacing equipment that is worn beyond repair. The tool supervisors request each replacement on a form called "request for equipment." On this request is given the reason for replacing the old machine tool, the repair-department records being used to show the cost of maintenance. At this same time, of course, there is also requested new equipment that is necessary because of improvements in the design of machine tools which make replacement advisable.

## Value of Records to Machine-Tool Builders

The complete and accurate records which have been kept at the Westinghouse works have been of great advantage to machine-tool manufacturers. In several cases where trouble has developed shortly after the machine tools were received the manufacturer has been notified and given a detailed report as to just what trouble was experienced and what was thought to be the probable cause and the cost. In this way the machine-tool manufacturer has been able to correct his design, if necessary, and avoid this trouble in other shops.

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### Weekly Inspection

As mentioned before, a semi-monthly inspection is made of all machine tools for cleanliness, proper oiling, and the need of repair. This inspection is made primarily for cleanliness and is usually held on Saturday afternoon after the shop has closed down for the week. All machine tools which are not properly cleaned or which are untidy in any respect are reported to the superintendent of that department and to the works manager.

By keeping the machine tools clean, we have reduced our maintenance cost and have added greatly to the appearance of the various departments. The weekly inspections have also instilled the idea of cleanliness throughout the entire shop and have resulted in proper cleaning and painting of the departments and also the proper arranging of material. The results of the maintenance system have been lower maintenance costs, less interference with production, and fewer accidents.

# Maintenance of Machine Equipment at the National Cash Register Company's Plant

By WM. HARTMAN,[a] DAYTON, OHIO

MAINTENANCE work at the plant of National Cash Register Company is divided into three classes:

1 General factory maintenance
2 Tool maintenance
3 Machine-equipment maintenance.

This paper takes up briefly the third class, machine maintenance work.

Following the company's general practice of specialization, this work is divided between four departments, each handling their own particular branch of work.

1 The general machine department repairs and rebuilds all machines, and takes care of all general machine-shop jobbing work.

2 The electrical department inspects and repairs all motors, wiring connections, and other electrical devices.

3 The millwright department inspects, installs, and repairs overhead work (countershafts, lineshafts, main drives, etc.) and belting. This department also moves all machinery.

4 The purchasing department coöperates with the above departments in securing the necessary replacement parts and furnishing up-to-date prices on new equipment when there is a question of whether to repair or replace.

There is no one department responsible for the condition of machinery in this plant. Each production foreman is held strictly accountable for keeping his machinery in first-class shape. All orders for repair work on machinery originate in the production departments and bear the foreman's signature. In order to keep a responsible check on this work these orders are approved by the division supervisor and general superintendent. Each order bears an order number, and costs are kept on this work by the comptroller's department through time cards turned in by the mechanics.

There is no budgeting of repairs in this plant because, due to the closeness of the work, machinery must be kept in perfect condition and it is felt that a budget would tend to keep a machine in use longer than its mechanical condition might warrant, resulting in bad work and dangerous conditions for the operators.

The necessity of repairs is determined by the foreman and his assistants in two ways: (1) A regular inspection of certain types of machinery, deemed particularly important or dangerous, and (2) by continual daily inspection and observation on the part of the foreman, job foreman, job setter, and operator on all types of general manufacturing equipment.

[a] National Cash Register Company.

### Machine Inspection and Repair

The machines covered by regular monthly inspection include punch presses, commissary equipment, scales, and certain types of special machinery. These machines require the attention of experts to keep them in working order and in some cases would cause a serious accident or tie-up in the production schedule in case of unwarned-of breakage. Where possible, a machine of this type needing repairs is run overtime. The increase in production thus gained allows the machine to be shut down for the necessary repairs. Where this is not possible, as in power-house equipment, the repair work is done during overtime.

The monthly inspection of punch presses, because of their dangerous nature, consists of a general inspection of the machines and a detailed inspection of all wearing parts which might cause an accident, such as clutch blocks, trips, clutch plungers, and springs. Any unusual noise or sluggish movement of parts is immediately reported to the foreman and the machine is shut down. A mechanic, who is a member of the general machine department, is stationed in this department and is always available for running repairs on this type of machinery. If the condition of the machine warrants it, the machine is taken out of commission and either sent to the general machine department or, in the case of a very large machine, is repaired on its own foundation.

Machinery covered by the second class of inspection consists of screw machines, mills, drill presses, lathes, etc. which are constantly being watched by every one who comes in contact with them and are repaired whenever they require it. Their work is transferred to other machines of the same type while they are out of service.

Because of the large number of screw machines in use in this plant and the complicated nature of such machines, a comparatively large assortment of replacement parts is carried in stock. The particular parts and quantities carried have been determined by past experiences. Extra spindles of Brown & Sharpe machines are always on hand, and as soon as one requires attention it is sent to the general machine department for repairs, an extra spindle is substituted, and the machine is put into service again at once. Standard sizes have been established for reground spindles, and bronze bearings are carried for each size so that when substituting a repaired spindle the proper size of bearing is always available. This same idea is carried out wherever the nature of the machinery requires it.

When machines are sent to the general machine department for repairs due to wear, they are inspected for the cause of wear and the weakness is remedied and the errors due to wear corrected. If this is not done experience has shown that the same machine may be back for repairs in a short time. It is sometimes necessary to substitute a different kind of bearing such as bronze instead of babbitt or even a ball bearing at times. A bearing may wear too much on one side. Replacement may get the machine into service again, but the way to keep it in service may be to provide a better support for the bearing or to make it longer. The aim is always to make the repaired machines as strong as possible in the known weak places. Where parts cannot be strengthened by better design, due to the conditions in the machine, an effort is made to produce the part in a stronger material. For instance, cast-iron dog carriers used on a certain type of machine are replaced by cast-steel parts whenever one is sent in broken. They last much longer and save their cost

many times over in production time. Repair parts which do not show marked weakness in design are purchased whenever it is cheaper to buy them than to make them.

When, in his survey, either the production foreman or the general-machine-department foreman find that the cost of repairs is excessive, they recommend to their supervisor that the machine be abandoned and a new one purchased to take its place.

This plant has an annual two weeks' vacation, during which period the entire production is shut down. This period is utilized to give all machines which run continuously a thorough inspection by the general-machine-department mechanics, and all parts which show signs of wear are replaced. Some time before vacation a survey is made of all departments, and machines which are known to need repairs are listed. This enables the machinists to do considerable preliminary work in advance. A great deal of power-house repair work is done during this period.

### Lubrication

One of the least expensive things that can be used in a machine shop is oil. It is very important that all machines be oiled regularly. Each operator is responsible for the oiling of his own machine. If he is a new man or an old man being placed on a new machine, he is first given thorough instruction in oiling and his machine is inspected by his job foreman for a few weeks, to see that it is taken care of properly. Extra-large oil cups are provided and, where practical, automatic oilers are installed. With the grade of operators employed by the company, experience has shown that in place of neglecting to oil, there is a tendency to use too much oil. However, it is better to have this condition than not enough.

This method of oiling machines is in use in most departments where an operator is on one machine only. His responsibility is easily fixed. In a few departments where different machines may be used by many men in the course of a year and where work is of a very accurate nature, such as for instance the toolmaking department, it has been found best to have an experienced man devote his entire time to the oiling of machines.

All overhead work is oiled by regular men from the millwright department. Except in special cases, countershafts are oiled twice a week while lineshafts, due to roller bearings, are oiled once every two weeks. At one time electric motors were oiled by a man from the electrical department, but at present the regular oiler takes care of this work. If there is too much or not enough oil used the man who inspects each motor daily calls this to the oiler's attention.

### Electrical Department

The electrical department repairs all motors and electrical work and specifies all new equipment, thereby maintaining equipment standard and lessening the amount of maintenance work in the future. Emergency repairmen have stations in different places throughout the plant to take care of small repair work.

There are approximately fifteen hundred motors in use, and an average of one hundred are rewound each year. Motor equipment is held down to as few sizes and types as possible, and in most cases there is a spare motor in stock for each ten to fifteen motors in operation. Should a motor break down there is on hand one to take its place. Where a special motor is necessary on some important equipment which might tie up a production unit, there is a spare motor for each one in active use. Repairs are promptly made so that a re-occurrence of the breakdown can be quickly taken care of. Each motor is inspected once every day, and a thorough examination and efficiency test made once each month.

### Millwright Department

The millwright department installs and maintains all countershafts, lineshafts, and belting, and furnishes oiling service and emergency belt-repair service. A telephone call brings an expert belt man on a small electric truck, equipped with a supply of belting and repair tools. All machine work on countershafting is done by the general machine department.

The entire maintenance program of this plant is planned to strengthen the weak places before a breakdown occurs and when a breakdown is encountered, the cause as well as the damage is corrected.

# Maintenance of Shop Equipment

By C. S. GOTWALS,[6] PHILADELPHIA, PA.

MODERN industry demands that shop equipment be kept in good condition for operation, and keen competition requires that new equipment be purchased as soon as it will pay for itself in a reasonable length of time.

For the greater number of productive machine tools a conservative estimate of the rate of wear can be made so that repairs can be attended to when they cause the least amount of confusion in the shop. In the Hess-Bright shops repair expenses are budgeted and repairs are made when convenient, emergencies excepted.

The departmental foreman and the accountant confer for the purpose of making this budget. The foreman knows approximately the amount of money needed for repairs, while the accountant translates this figure into a percentage of the productive labor in that department. Thus the amount of money allowable for repairs as per the budget will depend upon how much productive labor is in the department. Realizing that a repair has to be made, the production manager and the chief of the repair gang confer, so that a definite understanding is made concerning the exact nature of the repair and the approximate date when the machine will be back in production.

The departmental foreman knows when the machines need repairs, mainly because of the inspection given them by the repair chief. The inspection of the machine tools takes place periodically, their condition being reported to the foreman. Thus repairs are predetermined and intelligently made.

Whenever it is necessary to make repairs, the machine is taken down by the repair gang. The parts which have to be replaced are sketched by the drafting department, so that a permanent record is kept on file of that particular part. Many times when a machine has been taken down it is found that a slight alteration in the design of the part will increase its life. Other times a better grade of material is used in making the new part, thus tending to keep the machine in production longer. It has been found that it is desirable to replace worn cast-iron gears with steel gears, to replace plain bearings with ball bearings, to use hardened steel instead of soft steel, etc. Quite frequently upon analyzing the cause of a repair it is found that the part in question was not properly lubricated. This part is then redesigned to give better service.

### Lubrication

It has been found desirable in the case of large machine tools to put the lubrication of them under the supervision of the maintenance engineer. There are therefore men in the shop whose duty it is to see that the machines under their care are properly lubricated at all times. In this manner some cases have been discovered in which it was necessary to change the

[6] Time Study Dept., Hess-Bright Mfg. Co. Mem. A.S.M.E.

nature of the lubricant, while in others it was necessary to change the construction of the lubricating system. In the case of the smaller machine tools, the individual operators are expected to oil each machine whenever it is started. The precaution has been taken of preventing dirt from getting into the bearing surfaces along with the oil wherever possible. This is usually accomplished by filtering the oil at the point of its entrance into the bearing surface. It is quite true that a great quantity of dirt can be found in the ordinary shop oil can, which is constantly being used wherever production machinery is kept in motion. By preventing this dirt from reaching those parts of the machine where it would do considerable damage, a substantial reduction in the repair bill has been made.

### Division of Repair Work

Wherever possible, repair work is subdivided into groups so that one repair man or group of repair men will work on the same or similar equipment constantly. Thus for large machine tools one man is directly responsible for their proper repair when they have to be taken down. In this manner he learns to know the weak parts of the machine and is thereby enabled to make suggestions for the strengthening of these parts. There are also chief repair men in several departments, who, working under the supervision of the general foremen, are responsible for the proper repair of the machines in their respective departments.

The repair of grinding-wheel spindles has been specialized. That is, the spindle repair man works on nothing but spindles. There was a time not so long ago when each grinding machine was equipped with one plain-bearing spindle. Then, whenever it became necessary to "take up" the spindle the operator lost considerable time and a loss of production occurred. If this plain bearing had to be scraped, it of course took considerably longer. At the present time, however, these same grinders are equipped with ball-bearing spindles, and when it becomes necessary to adjust them, the spindle repair man immediately takes out the spindle that needs adjustment and replaces it at once with another spindle which has been adjusted in the spindle department. The spindle needing adjustment is then taken to the spindle department, where it is put into condition for operation. There are always enough spare spindles on hand, so that a machine operator loses a minimum amount of time and production when his spindle goes bad.

There are also repair men who specialize on the repair of punch-press dies, and others who do nothing but repair forging-machine dies. These men keep a record of the total number of pieces produced from each die as well as the number produced after each repair. In this manner a record is kept of various makes of materials used in the manufacture of the dies, whereby it is possible to find the desirability of changing from one kind of material to another.

### Replacement Policy

All of the foregoing concerning the repairs quite naturally leads to the question, When is it more economical to purchase new equipment than to repair the old? When the cost of repairs to any machine per year approaches 20 per cent of the cost of a new machine, new equipment is looked over. Or it may be found that the new machine, due to its improved design, will produce more or better work than the old, thus making a saving in labor. If the saving in labor plus the saving in the repair expense will pay for the new equipment in two years, it is considered a sound investment. Before purchasing any new equipment, however, it is ascertained that the old machine cannot be improved nor altered to make it worth while to continue to operate economically. Sometimes in this manner it is found that the possibilities of the old equipment have not been fully developed, and new equipment should not be purchased.

## Discussion

J. E. Webster.[7] The question of what should be done and what should not be done in a maintenance line is a very important point to decide. The quantity of the work to be done and the quality of the work to be done, are subject to great variations in judgment. A building will house an activity if the roof is in rather bad shape as long as it does not leak, and if the windows rattle, and if it is not painted, and if the floors are bumpy. Whenever officials of a company go through a plant the thing that impresses them as favorable or unfavorable toward the operating officials is the appearance of the plant, the cleanliness and the general neatness and quality of the maintenance work and how well the floors and stairways look.

The best way to handle maintenance is to have each type of work, such as painting and repairs to floors, repairs to roofs, maintenance of cranes, etc. budgeted for the year, and all work charged to an account number so that the man in charge or the plant manager can at the end of each month see what has been spent on that line of work. The man in charge of maintenance must "sell" the budget to the executive so that it will not be necessary to get approval for each item. If he can persuade the executive that he must spend so many dollars a month on each one of these items during the year to keep the plant up, then he can be made responsible for the selection of the various items to be done.

A. L. DeLeeuw.[8] Mr. Chapman speaks of the necessity of considering whether a machine should be disposed of or repaired again. This point is well taken. It takes more than a mere view of the machine itself to determine what to do. A look must be made into the future on the matter of obsolescence, which is so closely connected with the matter of repair that the one should never be considered without the other.

K. D. Hamilton.[9] It is indeed gratifying to see that the subject of maintenance has been brought up from a professional point of view. Maintenance has become today an engineering profession. Years ago it used to be that a Jack-of-all-trades fixed belts, stopped leaks in pipes, repaired boilers, and started up engines. Today, in the large plants, a man has charge of the entire organization, and the managers of the plants today should be convinced that the maintenance department can pay for itself. It should be run as a business. It should be able to compete with outside contractors. It should show a profit and can be proved to show a profit. Business methods should be organized throughout the entire department.

There should be a budget, a system of records of costs, and of prorating those costs among the various departments. The maintenance engineer, or the plant engineer as we should call him, should be an executive equal in standing with the superintendent, directly responsible to the management. He should sell his services as a high-grade executive. He should have charge of heat, light and power, buildings, plant, maintenance of machinery, new construction, and purchase of equipment in cooperation with the purchasing department. He should be able to function as a man who can handle labor, and above all he should prove to his management that he can make a dollar instead of spending it.

If accurate costs are kept of all phases of maintenance, each

[7] Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

[8] Consulting Engineer, New York, N. Y. Mem. A.S.M.E.

[9] Mechanical Engineer, Geo. E. Keith Co., Brockton, Mass. Mem. A.S.M.E.

job assigned to each particular number, maintenance men need not fear the point of view which is so readily taken by most managers, that the maintenance department is an unnecessary evil.

M. Sklovsky.[10] The problem of maintenance is so varied in its application—from buildings to the grinding of tools—that the same rules do not apply to all kinds of maintenance. I desire, therefore, to confine my remarks to machine-tool maintenance.

In more recent years the use of machine tools for production purposes has increased so radically that more machines today are used for production purposes than for maintenance purposes. A machine tool originally was a maintenance tool. We have made estimates in recent years and have found that on the basis of metal removed, the amount removed by a production machine was over fifty times that removed by a maintenance machine, so that on the old basis of putting in a new machine and having it last for 25 years it would result in a new machine's lasting only 6 months on heavy production work. It is obvious, therefore, that machines wear out much faster than they did years ago when they were used for lighter work and for maintenance work.

The cessation of production on account of shutdown of machinery is too serious a matter and need not be discussed. It is obvious. The user's problem is to acquire machinery that will stay conditioned the longest possible time and can be maintained in the readiest manner.

Two factors which have been referred to by the persons presenting the papers are very essential. One of them is lubrication. Lubrication—the proper kind of lubrication—assures the longer life of the machine. The haphazard way in which many plants provide rules for lubrication is such that in many cases lubrication is not applied in the proper amount nor with regularity, and for this reason machine-tool builders should definitely provide for the lubrication of all essential wearing parts.

The next point which machine-tool builders will be forced to take into account is the proper kind of bearings, and also, of course, the right kind of driving parts such as gears, etc. Bearings, however, are the most important as we see it. We specify, almost exclusively, roller bearings or ball bearings as the case may be, not from the standpoint, as is usually assumed, of saving power; that is an insignificant point and does not cover the extra fixed charges on added investment, but because roller bearings, for example, can be held in proper location and can be tightened up, and because instead of repairing such parts we prefer to replace them. Replacement of parts can be done readily, sometimes in a half-hour or at most a half-day. The overhauling of a machine with the old type of bearings may take anywhere from three days to three weeks, and during that period the machine is out of commission. We have, therefore, in purchasing equipment stressed the item of bearings that are to go with these machines, and we have found it advisable to pay an added sum for machines so equipped.

As to the organization back of maintenance, we find that the foremen of departments are too overloaded with production problems to be depended upon for the follow-up of maintenance. We leave that entirely to a separate department which has the responsibility for the condition of the machinery. The department foreman may report needed repairs, but he is not held responsible for the condition of a machine.

J. S. Packard.[11] Speaking from a designer's point of view, I should like to hear from some maintenance men who are confronted with the problem of keeping the machines going all the time, what are the faults with machines. Just where do they break down? What are the causes of breakdown?

The subject should be brought right back to where the troubles may start, and that is on the designing board. The man who designs the machines often does not know or cannot conceive the conditions under which those machines are going to be used, and I think I speak for most designers when I say that they personally would be glad to know of the things which cause breakage so that in the future designs they can have them in mind.

Then there is the question of guards. There is really no reason why a designer cannot guard all the moving parts properly unless he wants to close his eyes to the problem or wants to design a machine too cheaply. It is just a question of the viewpoint which the designer has.

There is the factor of gears. A man may design cast-iron gears or steel gears without any consideration of the actual work the machine has to do, nor can he conceive of some of the possibilities of hardship that they may have to endure where a little extra-carbon steel or chrome-nickel steel would make the life of that machine longer.

E. F. DuBrul.[12] I was in an automobile plant some time ago and saw many automatic lubricators attached to machine tools. They had been put on by the automobile company at great expense. They had been installed so that the operator would not have to look after the details of lubrication. Two and three hundred dollars per machine were quite common figures for the cost of installation of these lubricating systems. However, I have been told that the automobile manufacturer was not particularly favorable to the idea of paying two or three hundred dollars extra for the machine tool with the lubricator built in to save him the trouble of putting it on.

One speaker has just remarked that in the matter of removing metal the production tool of today removes fifty times as much metal in a given life as was removed by the maintenance tools of some years ago. I am reasonably certain that none of you are paying fifty times as much for those tools. I am sure that no machine-tool builders are getting fifty times as much for the tools that they are selling today compared to those of early days. But there is the performance.

The more automatic, the more complex the machine gets, the more trouble is built into the machine. I don't suppose it can be helped. Even a large plant having a very well-organized maintenance department will have difficulty, I think, in keeping expert service men capable of knowing all the kicks and quips of all the different kind of complex machines that they are getting in their factory.

Now, who is going to pay for the added expense of service made necessary by the complexity of these machines? Eventually the user has to pay for it. If the builder today does not charge for it he will not be building machine tools after a while. The builder of the future will charge for it, because the builder that does not charge for it today will be out of business after a bit.

Is it fair to put that service charge into the price of the machine, to spread it into the overhead? I don't think so. While that might be an easy way to cover it up, I don't think it is fair to users who are more competent, more careful of their machines, and who do not call for service. Why penalize the user who is efficient and make him pay more for a machine to cover up this sort of factory service by concealing it in the price? The fair thing all around is to charge the man who gets the service, and not to charge directly or indirectly the man who doesn't call for it.

[10] Chief Engineer, Deere & Co., Moline, Ill. Mem. A.S.M.E.

[11] Philadelphia Machine Tool and Sizing Co., Philadelphia, Pa.

[12] General Manager, National Machine Tool Builders Association, Cincinnati, Ohio. Assoc-Mem. A.S.M.E.

A. A. Richardson.[13] Service, generally speaking, is worth paying for. Equipment ought to have service when necessary, and then it is usually asked for. This plan appears much better than to believe it hidden in the price of the machine and paid for whether needed or not. Our plant, however, is more or less independent of the manufacturers' service because of the character of our organization. In many transactions it appears that service is neither more nor less than a good piece of sales argument. Some manufacturers do not regard it so, because we have service men who come to assist in our maintenance work voluntarily. We, of course, have to assume that the cost of it goes in on an annual overhead basis in that company's accounting.

In the National Carbide and Carbon Corporation maintenance is budgeted. In some plants it has been brought to a fine point where it is figured down to the individual machine, and we take that individual-machine maintenance cost over the year as representative of its next year's cost. We analyze that cost, of course, to determine both improvement and obsolescence, one or the other determining the disposition of a machine which is costly to maintain.

In maintenance work, I have been confronted by the problem of encouraging a maintenance force to reduce the cost of maintenance. As a rule the mechanics in the maintenance department are men who are more or less independent of your employment, because nearly all industrial plants have a maintenance crew to take care of the machines and the opportunity for another similar job is good. They also almost always possess a fairly good set of tools, and so can move from one plant to another without much loss. Some of them are expert mechanicians. But they are all paid on an hourly basis. I have inquired to find if time study and management have been applied in maintenance departments to assist in reducing maintenance costs and improving the earnings of the personnel. I have not found it yet. If the incentive of the piece-work rate can be applied to maintenance production, I am sure it will be profitable to all maintenance engineers as a means of reducing costs and improving the quality of the work.

D. R. Long.[14] Our maintenance problem is slightly different from that of the manufacturer of machine-tool equipment, for it consists of maintenance of tools we have designed and built. For that reason about eight years ago we started to chart repairs according to the cause. The cause of a given repair was ascribed by the men who made the repair and their foremen. It was surprising to learn the great number of repairs which could be ascribed to lack of proper lubrication. We found that from 3 to 40 per cent of the repairs charted each month could be attributed to lack of proper lubrication. Over five years it averaged about 30 per cent. Our repairs at that time were running about $400,000 a year, so you see there was a very appreciable amount of money spent for faulty lubrication.

We took the second step, then, to overcome some of the troubles. We organized a lubricating force. We withdrew from all the production foremen and all the machine operators the duty of lubricating the bearings on the machines. Since we organized that force four years ago there has not been a drop of oil kept in a storeroom in any production department. Lubricating men, eleven of them, under the direction of a competent foreman, trained as junior lubricating engineers, have charge of that work. They not only apply the oils and greases to the oiling devices, but select the kind of oil to be used on the particular bearing, and select the type of oiling device which is to be used.

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[14] Chief Engineer, Armstrong Cork Co., Lancaster, Pa. Mem. A.S.M.E.

The third step we took was the selection of a high-grade manufacturer of first-class lubricating oils, and we purchase all our oils from that particular manufacturer. We came to the conclusion that while we might be able to select one lubricant from one manufacturer and another from another and so on all over the country, it would be better to stick to the one manufacturer. We found we could get better prices on account of the volume. We selected a company competent to furnish a satisfactory lubricant for all the bearings and surfaces that we had to lubricate.

The results were threefold: First, as we originally intended, we reduced maintenance appreciably—several times the cost of the wages paid to these men. Second, we increased production through reduction of shutdown time due to repairs, and third, we have been able to work with the engineering department through these lubricating men to get better design. The machines now are designed with some of the lubricating devices and oiling channels that are necessary to apply the lubricant. I think that the feature of maintenance is sometimes overlooked, but it has a very important bearing on reduction of cost, and certainly no maintenance engineer has performed his function unless he has tried to reduce the cost of repairs.

E. J. Kearney.[15] During the last 25 years there has been a revolution in production methods and a revolution in the design and building of machine tools. In the earlier period very simple machine tools were operated by very competent men. Now we have very complex machine tools operated by operators more or less competent. Naturally trouble arises in such a situation.

During this period of machine-tool evolution changes have come about very rapidly. If machine tools could be designed and manufactured without change for a period of years the question of supplying repair parts would be just as simple as it would be supplying repairs for the Model T, but it is not so. The pressure of competition means that almost every lot of machine tools embodies changes, and it is exceedingly difficult for the machine-tool builder to maintain complete records and complete sets of repair parts so that when the maintenance departments of these various plants make requisitions for them he can supply immediately the necessary repair parts.

This question of maintenance will become more and more important. In railway service it has been reduced strictly to a science. The railways classify maintenance strictly on the basis of the performance, and performance is an entirely different thing from what it was 25 years ago.

In all fairness to the user, machine-tool builders themselves through their association should formulate some scientific plan whereby the user, by applying that formula, can tell whether he ought to buy a new machine or repair his old one. There are so many variables entering into this question that it is quite impossible for a machine-tool salesman coming in offhand to answer it. Large factories, at any rate, have no excuse for not approaching the question from a scientific basis. A machine tool may produce three times as much as the one in use and do it better and still not be economical to buy, principally on account of the fact that the old machine may be used only one month out of the year.

There is one phase of maintenance which is often neglected, and that is noise. I was in a factory in one of the New England states just a few days ago, and saw some old machines running that were designed and built in the particular factory where they were used. Apparently they were functioning properly, but a pair of gears that transmitted the power from the pulley

[15] Secretary-Treasurer, Kearney & Trecker Corp., West Allis, Wis. Mem. A.S.M.E.

to the machine was so noisy that it must certainly have put the operators in no great length of time into a state of physcial and mental decline.

Geo. H. Ashman. For the last 23 years the General Electric Company has used the budget system successfully. Every year, revised each six months, the department manager prepares a budget of expense covering repairs and relocation of tools and machinery. He also submits an investment budget of the new tools, buildings, and appliances he may need in the coming year. He prepares this latter from a production estimate given him. Very seldom has this budget been exceeded.

In the last inventory we have 13,000 catalogued tools. At intervals an analysis is made of the repairs that may be necessary to keep them in running order, their fitness for the work they may be doing where located in the plant, and their obsolescence. Records of cost of repairs for each machine are kept. With these data, each superintendent, with his productive-hour capacity as a basis, prepares his budgets of expense and investment. They are subject to revision by the general superintendent.

There is a tool department in each section under the supervision of a tool expert and competent mechanics. A foreman reports to the general foreman that certain machine-tool repairs are necessary; if of a minor nature, this man inspects them and makes the repairs, if in his judgment it is advisable. The question of replacing an old tool with a new one is made by the superintendent of the section on a special request form to the general superintendent of the plant, who bases his decision to purchase largely on the data submitted, showing the productive or working value of the tool as a percentage of the price of the new tool.

W. H. Chapman. I should like to say a word about budgeting and also about the design of equipment. I know of a plant that is successfully budgeting what is termed direct expenses. This is forecast on the basis of the sales forecast broken down into a production schedule and then broken down into direct-labor standard hours which are estimated on a piecework basis to require a definite machine-hour production per month. The forecast is made under a three months' period but is definitely forecast for one month; by that I mean there are forecasts for two months ahead of the month under consideration. The method of arriving at the budgeting takes into consideration the machine-hours, as well as the direct-labor hours, for they are pretty much tied together, and the method used is to merge all of the direct expenditures for each particular operation. The expense forecast is based on the standard-hour forecast and specifies the amount of money to be spent on various accounts during the month.

Of course it will be realized that there must be a very intelligent interpretation on the part of the men who are creating this budget. They must not only be good men from the accounting standpoint, but they also must be familiar with the plant conditions, department conditions, and any special conditions which may arise which are largely a matter of past experience. That is, they must be able to tell what is coming due to performance in the past. In this particular instance the budget last ran between 90 and 100 per cent efficient over a period of months in meeting the forecast. Usually it runs slightly below the actual expenditures.

On the question of design of equipment I should like to stress two points: One is the application of the power drive to the machine, the other, the selection of bearings by the designer. We have more trouble with bearing failure and drive failure than with anything else. I think in all probability most machine tools in the past have not been designed to stress the cutting tool to its efficient limit. In other words, there is an economical rate at which a cutting tool may be employed in the operation, and the machine most certainly should be provided with a drive and bearings which will permit the cutting tool to be used to its utmost capacity, assuming, of course, reasonable wear of the cutting tool. I have in mind particularly grinding machines, which only recently have been developed so that the fullest capacity may be obtained and at the same time satisfactory performance life of the machine without breakdowns.

From the standpoint of lubrication I am an advocate of anti-friction bearings because they use a slight amount of oil and if they are properly installed the oil reservoirs are designed to keep the bearings properly lubricated, and also because of the fact that they can easily be taken out and other bearings put in. Why any operator should have to send to the machine-tool builder to replace a bearing is beyond my comprehension, for the average man should be able to make the normal adjustment without having to call on experts from the machine-tool builder. I should say in cases where this is done that the maintenance men are either behind the times in understanding modern methods, or are thoroughly incompetent from a mechanical standpoint, for there is nothing tricky or incomprehensible about any of the well-known types of anti-friction bearings.

J. R. Weaver. In regard to service, we get wonderful service from the machine-tool manufacturers on machine tools. At times we call their men on certain jobs, but we try to take care of any troubles as far as is possible ourselves. But it seems to me that there is something else necessary in the machine-tool business, and that is probably a closer inspection or a running of the machine tool before it is sent out. In quite a number of cases a machine tool has come into our shop with the gears meshed too tightly or with clutches that will not run at a certain speed. This shows that the machine was asembled and shipped without a proper operating test.

In regard to lubrication, we do not have a central department for lubrication, but we have a corps of men, demonstrators, who are specialists. Each man covers a certain kind of tool and he is responsible for that kind of machine tool throughout the shop. His duty is to train the operator to take the proper care of it. This idea of taking too much responsibility away from the operator is wrong, for he will not take the proper care of it. Teach him that that machine has to do a certain task, that it must be treated in a certain way, and that it must have oil in certain places, and he will be there to do it in case something goes wrong.

In regard to replacement, we keep what we call an open shop. We say that if a machine-tool manufacturer comes in and can justify the expense of new equipment on any job we will buy it. When you say "justify" that may mean several things. Ordinarily we say that if in two, three, or four years it will pay for itself we will replace it. It depends on conditions. The product may change in design and it would not pay to buy a special machine for that job if the design is going to change. If the product is of a stable design we will replace with modern machine tools, even though it may take five years or more to justify the expenditure.

We do not budget repairs solely, but we do budget expense. In other words, budgeting by production each superintendent is allowed a budget of so much to cover jigs, fixtures, small tools, rearrangement, etc. He is required to keep within that budget if it is possible. It is not always possible, but when it is not, he is questioned.

Although we have had no time study on repairs we are anticipating it. We have gone into time study on repairs of small

tools and it is working out satisfactorily. In our tool room we have to a great extent adopted the time-study plan. We are making a study of the repair department to adopt the same thing. It is going to be difficult. It will be divided into certain phases. One set-up will take down the machine, another will assemble it, and another will keep it in repairs. We hope to be able to take care of it in the future.

C. S. Gotwals. We find that it is quite desirable to filter the oil. Oil is often fed to the bearings by the ordinary drop system by the operators, and we find that by placing a wick directly below the reservoir the wick will feed the oil to the bearing as needed. This prevents dirt from getting into the bearing itself. It is also true in other types of machine tools where an industrial filter can be applied.

# Symposium on Hydraulic Feeds for Machine Tools[1]

## Characteristics of Hydraulic Feed and Drive for Cutting Tools

By WALTER FERRIS,[2] MILWAUKEE, WIS.

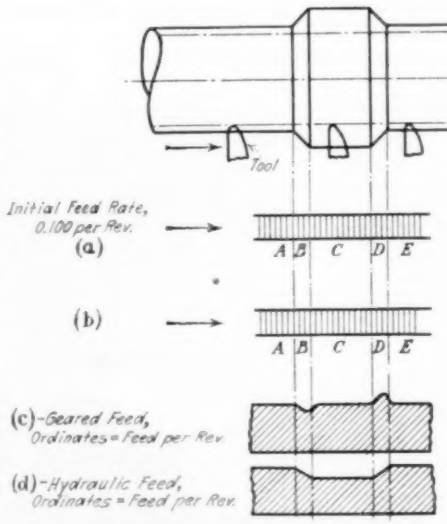
*In this paper the author attempts to show that the application of hydraulic feed and drive for cutting tools has been made possible by the return to the principles of the hydraulic method as it existed before the introduction of the accumulator, and through the introduction of the multiple-plunger pump. The general principles of hydraulic devices used for driving or feeding apparatus for machine tools are presented, particular attention being given to speed control and adaptability to control of inertia forces. The hydraulic drive may be applied either as a straight-line device or as a rotary device. Actual experience during the past five years has developed some peculiarities in the application of hydraulic feeding as compared with geared units, and these are described and discussed by the author. These peculiarities affect more the design of the tools than their field of application. In this connection the author describes the regulating devices and the various types of the application of hydraulic drive, in particular, variable-delivery pumps with closed hydraulic circuits vs. constant-delivery pumps with bypass circuits. He considers flexibility to be the most obvious peculiarity of hydraulic feeds, and illustrates by examples its value.*

IN CONVERSATION with machine-tool builders and users at the exposition in Cleveland this fall, it was apparent that many men who are interested in the evidently increasing use of hydraulic feeds are not yet thinking of the hydraulic method on its own merits. They are still comparing its results with the familiar performance of mechanical devices, and assuming the mechanical method as a standard with which oil-pressure devices are to be compared. There is now no reason why mechanical feeds and drives should be assumed to be superior to oil-pressure feeds and drives, and the two methods should be compared with the idea of visualizing more accurately the exact nature of the hydraulic devices, rather than with the idea of judging these hydraulic devices by comparing their results with the results obtained from mechanical devices.

Five years ago it was assumed that a broach should be pulled by a screw, and a hydraulic broach drive which showed a distinct jump as the broach teeth pulled through the work was immediately condemned for lack of steadiness. Obviously the performance of the screw was assumed as a standard to which the hydraulic performance should be compared. Today it is fully proved that for one reason or another the hydraulic machine is capable of pulling a broach from three to five times as fast as the screw machine, and that the broach will last longer. When hydraulic feeds were first introduced they were similarly compared with mechanical feeds, with the tacit assumption that mechanical feeds leave nothing to be desired. The large number of machines operating with oil-pressure feeds at the Cleveland show is sufficient evidence that there was something wrong with this assumption. Yet the most striking recent innovation—the oil-pressure feed on large milling machines—was strongly criticized because the feed was not perfectly steady and rigid in its advance. It showed elastic follow-up characteristics similar to those which experience has proved to be associated with especially successful operation in broaching machines, drilling machines, and boring machines.

These observations suggest the desirability of carefully analyzing the inherent properties of oil under pressure, taken from a multiple-plunger pump as a driving means. Such an analysis will lead us to examine and think of hydraulic feeds and drives on their own merits in view of the work to be done.

To understand the revival of hydraulic methods in power transmission during the past few years, it is necessary to consider the characteristics of the old hydraulic plants using accumulators,




APPROXIMATE FEED RATES

| | A | B | C | D | E |
|---|---|---|---|---|---|
| GEARED | 0.100 | 0.100 Reducing to 0.080 | 0.080 Increasing to 0.100 | 0.100 Increasing to 0.120 then Reducing to 0.100 | 0.100 |
| HYDRAULIC | 0.100 | Reducing to 0.075 | 0.075 | Increasing to 0.100 | 0.100 |

FIG. 1 GEARED AND HYDRAULIC MACHINE-TOOL FEEDS: EFFECT OF VARIATIONS IN DEPTH OF CUT ON RATE OF FEED

[1] A series of four papers contributed by the Machine Shop Practice Division and presented at the Annual Meeting, New York, December 5 to 8, 1927, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

[2] Vice-President and Chief Engineer, The Oilgear Company, Mem. A.S.M.E.

and to note that practically all the new applications discard the accumulator and substitute a high-speed multiple-plunger pump.

The accumulator method had become thoroughly discredited among engineers due to the uncertainty of control, the shocks and damage to the system from the operation of the accumulator and the throttle valve, and the extravagant consumption of power. Hydraulic machinery was rarely used when any other method was possible. The possibility of dispensing with the accumulator and going back to the first hydraulic principles was opened by the development of the high-speed variable-displacement pump, which would deliver large quantities of

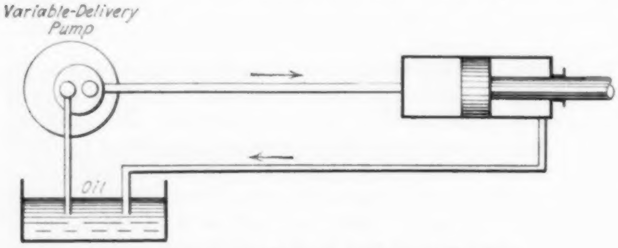



Fig. 2 Hydraulic Feed with Closed Circuit

fluid at high pressures when required, and would graduate the amount delivered exactly in proportion to the position of a control lever, and without regard to the pressure against which the pump operated at the instant. Probably because of the disfavor with which hydraulic methods have come to be regarded, engineers have been slow to realize that those methods are radically changing, and that the hydraulic method is now the only appropriate one for many an operation where it would not have been considered a few years ago. The perfect speed control where there was formerly no reliable speed control, the very high power economy where formerly hydraulic transmission was the most wasteful of all, and the great durability of the working parts running in high-grade lubricating oil and without heat, combine to make the hydraulic method more suitable than either mechanical or electrical methods of power transmission through a great range of applications. The above outlined facts underlie the increase in hydraulic applications, which has led to the assignment of the present session of the Annual Meeting exclusively to the hydraulic operation of machine tools.

The first hydraulic press was driven by a volumetric pump. At every stroke of the plunger the ram advanced a definite

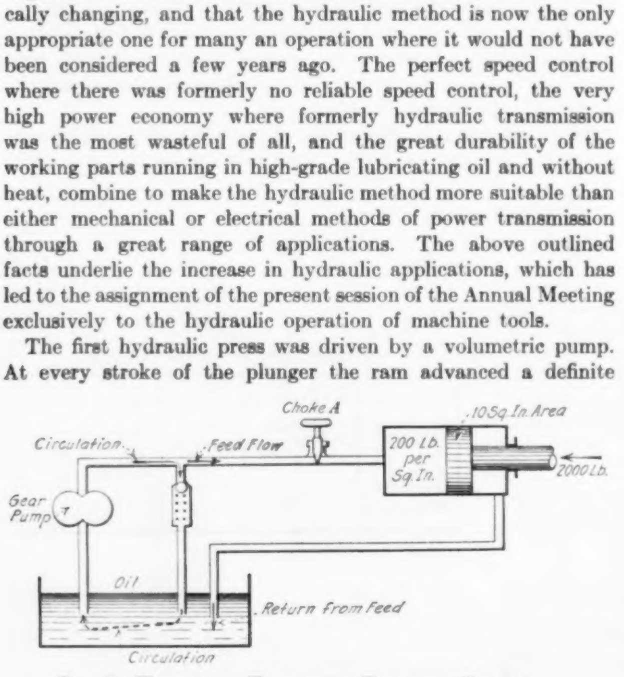



Fig. 3 Hydraulic Feed with Bypassed Circuit

amount. Also if there was no work in the press the pump operated easily, as it was only necessary to overcome the packing friction to advance the ram. If the press was used for baling cotton, the ram would at first move very easily, and as the cotton was compressed, the pressure would gradually rise to the maximum. Thus the original hydraulic press had a speed completely responsive to the rate at which the operator worked the pump, and the work required to drive the pump corresponded exactly to the work actually done in compressing the cotton bale plus friction. At that time, however, the available pumps delivered only very small volumes, and the accumulator was invented to enable this small pump to work continuously and store up its delivered volume. In this way the press could make a stroke in a much shorter time.

But with this change to accumulator operation, the original response of the ram to the pump and the economical performance of the work to be done were both lost. From that time every such hydraulic plant has used the maximum of energy for each stroke, whether the work required it or not. Also the speed at which the ram advanced became uncertain, depending on the opening of the throttle valve and the resistance encountered. The throttle valve introduced intense jet action, causing the minute quantities of abrasive in the liquid to rapidly cut the working parts. The wasted energy was also developed into heat as it passed through the throttle valve, resulting in further damage.

During the past five years considerable progress has been made in the application of hydraulic methods to machine-tool operation. Most of this progress is directly due to a return to the principles embodied in the original hydraulic press, before the accumulator was invented. The new hydraulic devices are driven by definite volumes of liquid delivered from each pump to its operating cylinder. The pressure is low if the piston encounters no resistance, and the distance moved by the piston corresponds to the discharge of the pump, whether the resistance be low or high.

## General Properties of Hydraulic Devices

In considering hydraulic driving or feeding devices for machine tools, the following list of general properties of these mechanisms may be helpful in determining their practicability, and assisting the designer to select the proper hydraulic apparatus.

Some of these characteristics are as follows:

(*a*) *High Efficiency.* This is illustrated by the efficiency of the hydraulic broaching machine, which is from three to four times as great as that of the screw machine. This might have

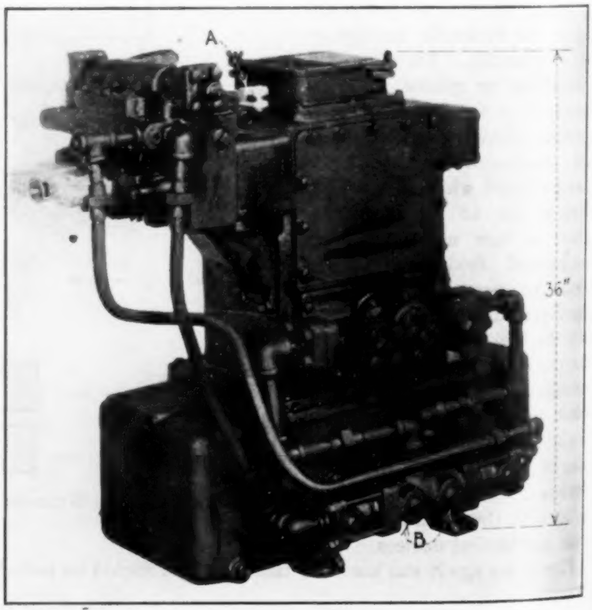



Fig. 4 Automatic Variable-Delivery Pump—Type WM

(*A*, 7-position control-valve stem, operated by cam plate on carriage; *B*, pipe connections to ends of 8-in. feeding cylinder. Pump provides two feeding speeds and rapid traverse in either direction. Capacity, 3060 cu. in. oil per min. at 1000 lb. per sq. in. pressure.)

been easily predicted, but the possibility led to no practical advance in the art for many years.

(b) *Speed Control.* This also has been much discussed, yet its importance in the future development of machine tools is not realized. As applied to feeds it permits the operator, without stopping the machine, to select at any moment the maximum feed which the work and tools will stand. At the Cleveland show the author saw one milling machine demonstrating the maximum application of power to cutting. In one case the feed was a little more than the machine could take. The motor was stalled and the demonstration stopped. With oil-pressure feed the operator would have gradually increased the feed by watching the ammeter for maximum power input. This was clearly illustrated on another machine at the same show. When applied to driving the spindles of lathes or boring mills, a complete hydraulic design will embody a minimum amount of gearing, and automatic hydraulic-gear shafting, so that the operator need only place a pointer on a dial at the figures indicating diameter of cut and cutting speed desired. The operation of such a headstock is explained later in Par. (h).

(c) *Lower Cutting Force.* It has been experimentally proved that a broaching tool working in a given material and at a given speed requires fewer pounds of force to pull it through the work in a hydraulic broaching machine than in a screw broaching machine. The power saving is of no importance commercially, but the fact may be of great significance in investigating the action of cutting tools.

(d) *Adaptability to Control of Inertia Forces.* The gradual change of speed due to the progressive stroke changes in the driving pump is of great advantage in handling heavy masses such as large grinder tables, which must be frequently reversed. This principle had many illustrations at the Cleveland show as applied to grinding machines and honing machines. Some employed closed circuits (see Fig. 2), in which the kinetic energy of reversal is transmitted through the pump to the driving motor. Such circuits may be either high-pressure or low-pressure, and both were represented at the show. Another method is to use constant-displacement, low-pressure pumps and motors, absorbing the energy of reversal by expelling part of the oil in the circuit through regulated orifices (see Fig. 3). The applications so far made would indicate this method for very rapidly reciprocating tables of comparatively small weight such as internal grinders. As yet there is little experience with the closed circuit on such work.

(e) *Flexibility of Design Conditions.* When designing hydraulic feeds it is not necessary to accurately specify the rate of feed required, which can be determined experimentally when the machine is operating. This greatly reduces the losses due to inability to foresee conditions, reduces the time and cost of the design, and increases the output obtained from the machine by facilitating experiment during production.

(f) *Standard Units.* Nearly all hydraulic feeding schemes

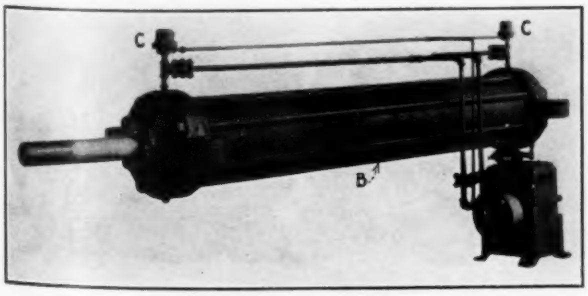



Fig. 5 Hand-Controlled Feed Pump and Cylinder

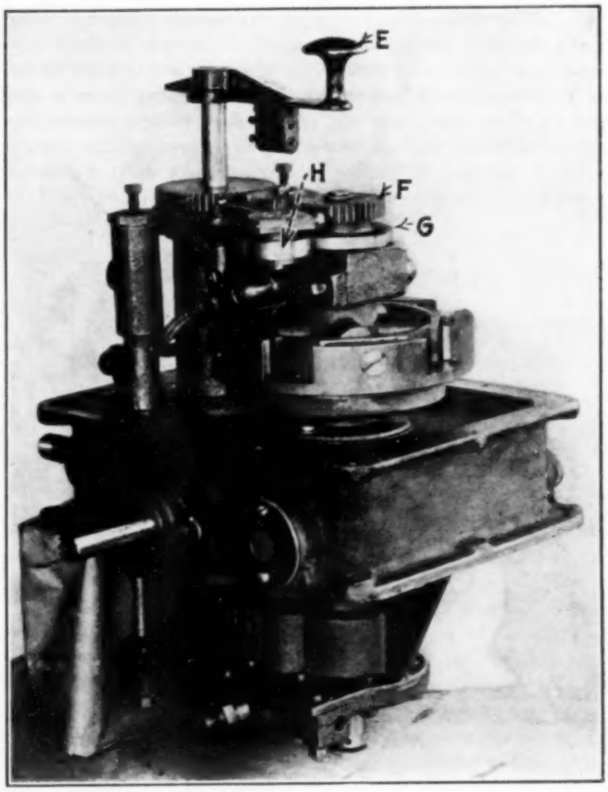



Fig. 6 Pump Removed from Its Oilpot and with Cover Off

can be carried out by using one or another of a series of standardized pumps with the appropriate standardized cylinder or rotary motor. The technic involves a knowledge of many different oil circuits, which are worked out and diagrammed in a manner suggestive of electric circuits.

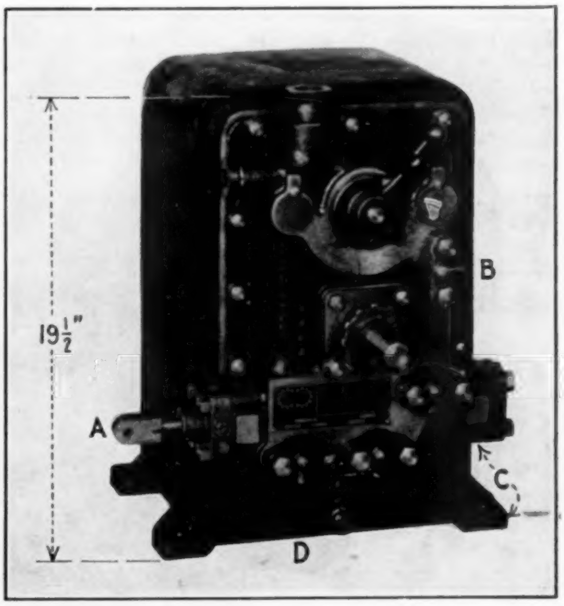



Fig. 7 Automatic Variable-Delivery Pump—Type QS

**(*B*, auxiliary circuit from gear pump to operate fixtures, etc.; *C*, main discharge and return connections; *D*, return from auxiliary circuit. Capacity, 550 cu. in. per min.; maximum working pressure, 1000 lb. per sq. in.; speed of drive shaft, 860 r.p.m.)**

(*g*) *Adaptability for Operating Auxiliary Devices.* Many of the standard feeding pumps available include in their construction a low-pressure gear pump which is used to supercharge the variable-delivery feeding pump, and in many cases is also used to effect rapid traverse. With such pumps connections may be taken out from the gear-pump circuit and used to operate auxiliary clamping devices for holding work, for shifting clutches or gears, or for any other desired function (see Fig. 8).

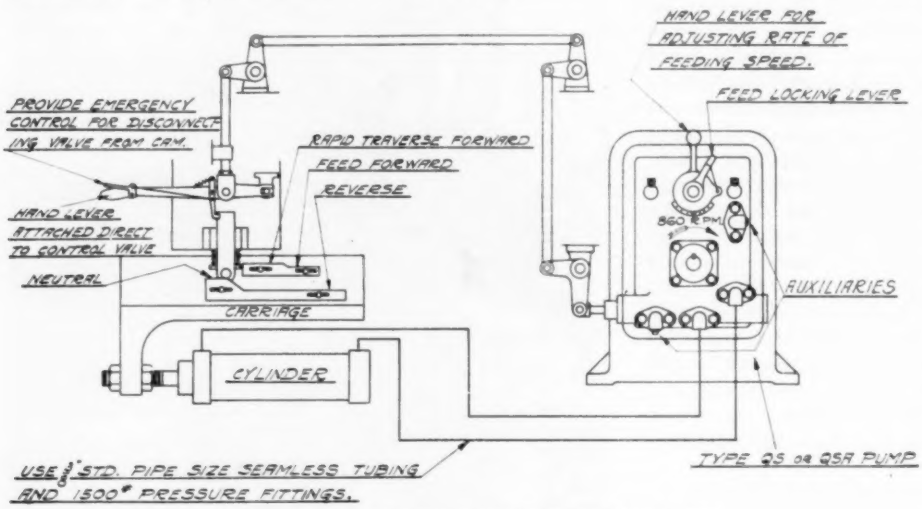



Fig. 8 Method of Operation of Control-Valve Stem

(*h*) *Straight-Line or Rotary Applications of Power.* Every hydraulic transmission consists of a driving pump and a driven motor. The motor may be a reciprocating cylinder, illustrated by honing machines, and in most of the feeds on cylinder feeding and boring machines. Or it may be a rotary motor, illustrated by the large face-grinding machines at the Cleveland show and by rotary-table milling machines where the motion is continuous. The rotary motor comprises the same running parts as are used in the corresponding pump, usually omitting the variable stroke. In the general case of spindle drives, however, variable-stroke motors will become almost as essential as variable-stroke pumps, because spindle drives characteristically require a constant horsepower input which can only be obtained when the pump is running at its full capacity. The speed variation will then be obtained by gradually reducing the motor stroke, causing the motor to speed up as the diameter of the cut is reduced. When the minimum practicable motor stroke is reached (about $^1/_2$ or $^4/_{10}$ stroke) the back gears may be automatically changed to the next faster ratio. The motor will be simultaneously returned to full stroke and the cycle repeated. On facing cuts the r.p.m. changes with the radius of the cut so as to automatically maintain a constant cutting speed. Such a lathe head has not yet been made, but is now only awaiting a machine-tool builder with the vision to appreciate its advantages when compared with the present typical lathe or boring mill. A 20-in. lathe with three sets of back gears may be carried through a range from 14 r.p.m. to 800 r.p.m. at practically uniform cutting speed and horsepower. The spindle would have to be mounted on ball or roller bearings to permit the high spindle speeds. These high speeds made available for small diameters of cut on a turret lathe will in themselves effect a material saving in production time.

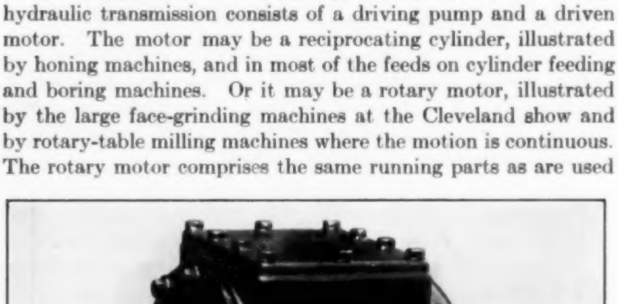



Fig. 9 Constant-Displacement Motor—Type RC

(*Standard:* Displacement, 4.6 cu. in. per rev.; max. torque, 690 in-lb. at 1000 lb. per sq. in.; max. speed, 860 r.p.m.; output at max. speed and torque, 9.4 hp. *Special:* Displacement, 6.08 cu. in. per rev.; max. torque, 920 in-lb. at 1000 lb. per sq. in.; max. speed, 725 r.p.m.; output at max. speed and torque, 10.6 hp.)

(*i*) *Operating a Plurality of Feed Motors.* To have complete individual speed control of two or more hydraulic motors, each motor must be driven by its own pump and the entire flow from the pump must go through that motor. If the flow is divided between two or more motors in parallel, the motor encountering the least resistance may take the entire flow of the pump until that motor has finished its stroke or is stopped by closing a valve in the circuit. Thereafter the motor next easiest to drive will go through its stroke, and so on. The total time required to put all the motors through their cycles will be the same as though they operated simultaneously.

Such an arrangement is indicated in Figs. 11 and 12. In this case the pump stroke may be changed to give any desired speeds while cylinder *B* is operating, and again adjusted for other speeds while cylinder *E* is operating. This is possible

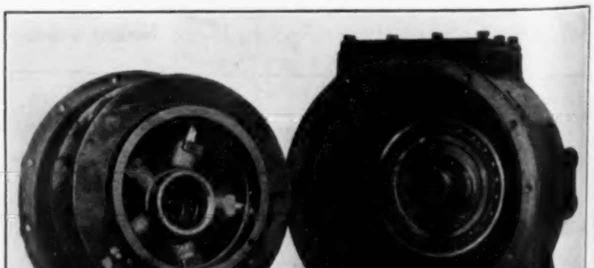


Fig. 10 Interior View of Motor Shown in Fig. 9

because the spring-resistance valves $C$ and $D$ really separate the parallel circuit from the pump through the two cylinders into a pair of individual circuits. The circuit leading to the clamping cylinder $B$ operates below the pressure at which the spring-resistance valves are set, while the circuit leading to the main press cylinder $E$ is operated only by forcing oil through these spring-resistance valves.

(j) *Cylinders in Series.* If the speed control required on two cylinders is simultaneous and proportional, the two cylinders may be placed in series in a closed circuit with a single pump. Such a circuit with three cylinders in series is indicated in Fig. 13. This circuit is applicable to a way drill with three drilling heads. Such heads are usually coordinated mechanically by racks and pinions or by linkage, but the hydraulic method is more flexible, safer against breakage, and in some cases may be cheaper. The three cylinders must be graduated to the speed requirements of the heads. If one head is to move twice as fast as another head, its cylinder must have one-half of the volume. Also, each cylinder must be so designed that the volume displaced in its piston-rod end is equal to the volume displaced in the head end of the next succeeding cylinder. This is evident from the diagram, as the oil supplied to the head end of each cylinder after the first one comes from the rod end of the preceding cylinder.

In order to keep such a set of pistons operating in coordination with each other, they must be arranged to run against the cylinder heads at the termination of each cycle, so that they always start the next cycle in the same relation. Hence the relief valves indicated in the diagram, permitting oil to pass around any piston which has stalled against its cylinder head during the back stroke, thus bringing all of the pistons successively back against their cylinder heads.

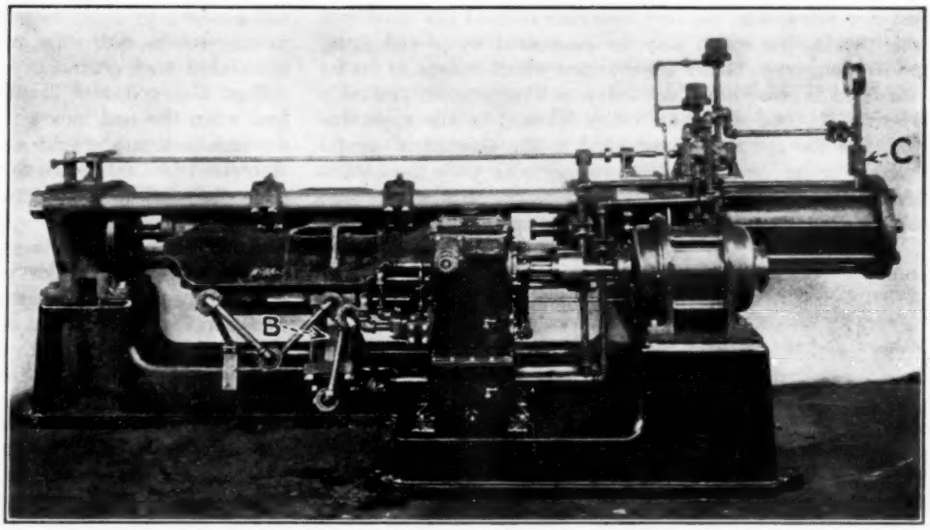



Fig. 12 Rear View of Press Shown in Fig. 11

(k) *Use of Multiple Transmitter.* The series circuit of Par. (j) divides the total working pressure into as many parts as there are cylinders. This reduces the maximum working pressure available in each cylinder, and tends toward large cylinder diameters. For this and other reasons it is sometimes better to use a multiple transmitter consisting of one double-acting cylinder reciprocated by the pump and operating several cylinders whose piston rods are attached to a single crosshead. Each of these secondary cylinders acts as a pump or impeller for its own individual driven or feeding cylinder. This system establishes several separate closed hydraulic circuits, each of which operates its feeding cylinder at definite speeds, the pressure in each separate circuit depending on the resistance against the piston rods of the respective feeding cylinders and on the corresponding piston areas. The strokes of all the impelling cylinders are the same, but their diameters and the diameters of the feeding cylinders may be varied to give any desired feeding forces and strokes to the respective feeding cylinders, provided the totals are within the power capacity of the pump. All speed variations and distances traveled by the pistons of the respective feeding cylinders are proportional to the speeds and distances traveled by the piston of the main cylinder connected to the pump.

In this case also it is necessary to provide means similar to those shown in Fig. 13 to bring each of the feeding cylinders against this cylinder head at the end of every cycle to keep the pistons in coordination. A system of this kind is indicated in Fig. 14, only the principal circuits being shown. In practice, the circuits of both Figs. 13 and 14 require low-pressure make-up lines from pump to each circuit, and other details which are omitted for the sake of clearness.


Fig. 11 Front View of 30-Ton Chevrolet Truck Axle-Assembling Press, with Automatic Clamping Fixture
(Clamping and pressing are accomplished with one movement of a single lever.)

### Inherent Characteristics of Hydraulic Feed

Actual experience during the

past five years with the new hydraulic method has developed some peculiarities which may be considered as proved facts, and has suggested others by evidence which cannot as yet be considered as proof, but which indicates directions for profitable experiment. Still others are really inherent in the apparatus used, but are apt to be overlooked in the absence of careful analysis, or to be clouded by comparisons with mechanical devices.

In the application of hydraulic feeding as compared with

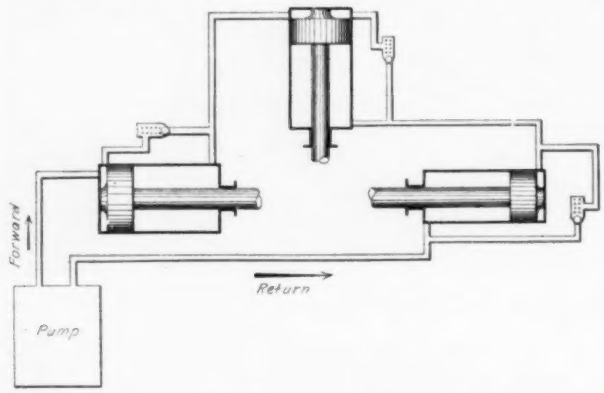



FIG. 13 DIAGRAM OF SEVERAL CYLINDERS IN SERIES

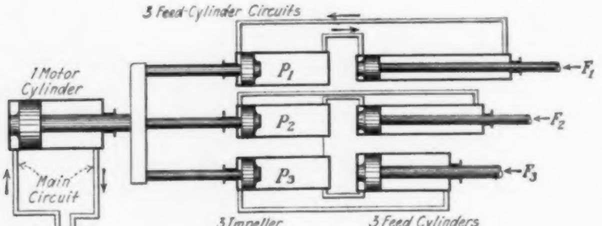



FIG. 14 DIAGRAM OF MULTIPLE-IMPELLER SYSTEM

(Rod speeds vary inversely as the respective piston areas. Pressures $P_1$, $P_2$, and $P_3$ vary with resistances $F_1$, $F_2$, and $F_3$, and inversely as piston areas.)

geared feeds, there are several essential peculiarities which should be taken in account.

(*a*) *Slip.* A tool holder fed by an oil-pressure piston and a volumetric pump cannot be used to chase a thread; and of course its rate of feed is not absolutely constant. There is always a certain amount of leakage (across the bridges and through the plunger fits) in the pump, and this leakage is greater as the cut gets heavier and the oil pressure rises. If the feed is small in inches per minute, this leakage may be a considerable percentage of the pump delivery. This is the "slip." In our early exhibits of hydraulic feed, visitors uniformly assumed that it was a defect. Geared feeds do not slip. The tool must cut the given thickness of chip whether the material is hard or soft, the cut deep or shallow. If the tool manages to back off slightly due to wind-up in the rods and gearing, the lost travel must be made up, and the average thickness of chip throughout the cut must be equal to the geared feed rate.

If the tool is fed by oil from a volumetric pump, it will never move faster than the nominal feed rate, but higher pressures will cause the feed to slow up more or less. The travel lost by this increased slippage is never made up. Hence the tool is not damaged by being forced to maintain the given feed rate, as may be the case when overload causes winding up of the mechanical feed gear.

Figs. 1(*a*) and 1(*c*) illustrate the action of a mechanical feed when the tool moves from a light cut through a heavy cut and back into a light cut. A temporary reduction in the theoretical feed rate when the tool strikes the heavy cut represents the wind-up in feed rods and other elastic parts. This wind-up progresses until it develops a sufficient increase in feeding force to compel the tool to resume its theoretical rate in the heavy cut. If the cut proves to be so heavy that the feeding mechanism is not strong enough, a breakage will occur unless some slipping clutch is provided. When the tool runs out from the heavy cut into the light cut, there is a temporary increase in the rate of feed above the theoretical rate, due to the unwinding of the feed rods, etc. It is thus evident that through the entire range from light to heavy and back again into the light cut the theoretical feed rate is maintained irrespective of the resistance encountered by the tool.

Figs. 1(*b*) and 1(*d*) show the radically different action of a cutting tool driven by a column of oil under pressure from a multiple-plunger pump. The pump has a fixed theoretical displacement which determines a maximum steady flow of oil into the feeding cylinder. This is the maximum rate of flow which the pump would deliver if there were no resistance to the feed. But in practice there is a certain amount of slip or leakage of oil past the pistons or other running fits of the pump, and past the piston in the cylinder. The rate of this leakage depends upon the pressure, and the pressure is directly caused by the resistance encountered by the tool. Consequently the flow of oil actually delivered by the pump into the feeding cylinder is less as the resistance increases. In actual practice this reduction of feed with increasing pressure may be a very significant fraction of the theoretical feed rate, especially with heavy cuts at slow feeds. For instance, a standard $3^7/_8$-in.-diameter feed cylinder has a piston area of 11.8 sq. in., and can deliver a net feeding force of 11,800 lb. to a cutting tool. When working at this maximum pressure of 1000 lb. per sq. in., the slip of the entire apparatus would quite likely amount to 15 cu. in. of oil per min. In ordinary cuts such a feeding cylinder usually operates at pressures of 250 lb. or 300 lb. per sq. in., and the slip is perhaps 5 cu. in. per min. Therefore, if the feed were ad-

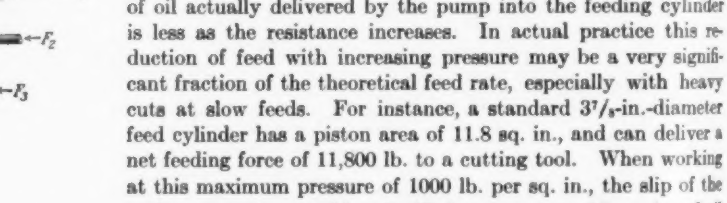



FIG. 15 SPRING-RESISTANCE VALVE

justed to give 4 in. per min. under 250 lb. pressure, the additional slip of 10 cu. in. of oil as the pressure rises to nearly 1000 lb. would reduce the rate of feed by nearly $^7/_8$ in. per min., leaving a net feed of about $3^1/_8$ in. per min. during the excessively heavy cut. This amounts to a 20 per cent reduction in the 4-in.-per-min. rate of feed. If the feed rate were set at 16 in. per min., the reduction would be 5 per cent, as the amount of slip is practically constant for given pressures.

The above figures of amount of slip are based on a type of pump having relatively large leakage through a distributing valve. Other types would show about one-half of the maximum slip.

Fig. 1(*b*) shows that this reduction in rate of feed continues during the entire period of the heavy cut. Also, when the tool runs out again into the light cut the slip of the pump reduces to the former figure, and the rate of feed merely returns to the original 4 in. per min.

(*b*) The foregoing examples show rather extreme variations in rate of feed for the sake of clear illustration. In ordinary cuts there is little change in the rate of feed during the cut. On the other hand, in heavy shaving cuts with a wide tool a still larger proportion of the pump delivery may be represented by slip, and such a cut may very likely end by stalling the carriage against a stop and delivering the entire flow of the pump through the relief valve for a few revolutions until the surface is finished and the tool withdrawn.

(*c*) *Follow-Up.* This is caused by the elasticity of the oil column and the cylinders and conduits which contain it. It would seem to be closely analogous to wind-up in the feed rods and other parts of a geared feed. But in the case of the oil column the amplitude is small and the action is practically frictionless. The effect seems to be to soften or cushion the peaks of feeding force applied to the tool. The author merely suggests the term for use in formulating convenient hypotheses to account for observed greater durability of tools under oil-pressure feed.

(*d*) *Vibration or Resonance in the Column of Pressure Liquid* which receives a rapid succession of impulses from the pump plungers. These impulses have a frequency of from 100 to 200 cycles per second, depending upon the number of plungers and the speed of revolution. Although the rate of flow from the pump is almost uniform, these pressure impulses are very evident at high pressures on an unprotected pressure gage. In high-pressure broaching cuts, the shape and appearance of the chips are also distinctly different when the tool is actuated by oil pressure. The author has reflected on the fact that a man's hand can push a chipping hammer through a cut which, in the absence of the little hammer blows, would require a planer. Possibly there is something analogous in the effect of the tool carriage impelled by the elastic oil column, with the pump imparting impulses to the other end of the column.

(*e*) The intensity of these impulses varies with the pressure, and for such work as grinding, the working pressures must be kept low enough to avoid perceptible vibration which may mark the work. This condition tends to favor the gear pump for reciprocating small grinder tables, as the gear pump is normally a low-pressure unit. However, the gear pump itself has a strong tendency to transmit vibrations, which are probably somewhat damped out by bypassing a part of the discharge through an orifice. The disadvantages of the gear pump are already leading some grinder manufacturers to experiment with low-pressure pumps of variable capacity, to get a definite series of table speeds. This entire phase of the hydraulic-feed art is rapidly developing. It seems likely to the author that grinders of the heavier types will tend to be driven by pumps of definite displacement, with closed hydraulic circuits.

(*f*) *Stalling.* The ability to stall against an obstruction protects the parts against breakage and at the same time provides an ideal method of locating shoulders, facing to length, etc. The relief valve on the pump may be set to limit the stalling force to any desired amount.

(*g*) *Pressure Readings and Regulating Devices.* The pressure gage on either a feeding or driving circuit gives important control over the operations. Dulling of tools is clearly indicated before breakdown of the cutting edge. This is particularly valuable where expensive milling cutters and broaching tools are being used. The habit of watching the pressure gage is now bringing results in controlling the use of tools which will have a strong influence in extending the field for the hydraulic drive.

Various protective and governing devices may be operated by the pressure in the circuit. Broaching machines are equipped with an overload circuit breaker, which may be set to open and bypass the pump discharge when the pull on the broach exceeds any desired limit. Feed pumps are available which will automatically reduce their stroke as the pressure rises. These may be employed to give a gradually reducing feed when cuts become excessive, as in the large fillets in castings and forgings.

Other regulating devices include a time-limit relay in the form of a dashpot attached to the valve gear of an automatic pump. This delays the actual carriage reversal after the feed reverse has tripped, and gives an adjustable time for completion of a facing cut.

### Variable-Delivery Pumps with Closed Hydraulic Circuits vs. Constant-Delivery Pumps with Bypassed Circuits

All of the preceding remarks on the characteristics of hydraulic feed are based on the use of a variable-delivery pump having an adjustable stroke, so that it is set to deliver only the exact amount of oil required for the given rate of feed, plus unavoidable leakage. Fig. 2 illustrates the oil circuit in such a case. For the sake of simplicity the figure shows the pump pushing the piston outward, and omits a valve which must be used to interchange the discharge and return pipes on the in-stroke. It is obvious that this arrangement gives a definite rate of feed proportional to the metered discharge of the pump, less leakage from the closed pressure side of the circuit through the pump pistons and the feed piston. It will also be clear that the rate at which the piston moves will never exceed the rate corresponding to the fixed discharge of the pump, and that greater or less resistance to the movement of the piston will only raise or lower the pressure in the cylinder and connecting pipe to the pump, without materially changing the speed at which the piston moves.

Another type of circuit is extensively and successfully used for reciprocating grinder tables, etc. as mentioned earlier. Such a circuit is illustrated in Fig. 3, showing a gear pump pushing a piston at a rate corresponding to only a fraction of the displacement of the gear pump. The excess displacement escapes through a relief valve into the oilpot and is again taken up by the gear-pump suction pipe and continuously circulated. The pressure in the pipe leading to the cylinder is set at 300 lb. per sq. in. by the relief valve as indicated. As the oil flows through the choke $A$ (which may be an adjustable needle valve) it falls to whatever pressure is required against the piston to overcome the mechanical resistance. As shown in Fig. 3, this pressure is 200 lb. per sq. in. on a piston of 10 sq. in. area to give a feeding force of 2000 lb. Under these conditions, the flow through choke $A$ corresponds to 100 lb. net pressure, determining the rate of flow which will furnish 200 lb. pressure against the piston at the rate of feed for which choke $A$ is adjusted. When the drills break through, or the mechanical resistance is otherwise removed, the pressure in head end of cylinder drops from 200 lb. to 0, and the flow through choke $A$ immediately changes to the rate corresponding to 300 lb. net pressure instead of 100 lb.

If the load to be driven by the piston of Fig. 3 consists of a grinder table weighing 500 or 600 lb. and carrying a grinding wheel whose total feeding resistance against the work is perhaps 10 lb., the load is principally due to inertia and is almost constant, and this type of circuit is distinctly applicable and its advantages are properly weighed by the designer against the advantages of the closed circuit of Fig. 2.

As the bypassed circuit with an inexpensive gear pump is

extensively used for reciprocating tables, it is natural to infer its applicability to hydraulic feeds for drill presses and boring machines. As a matter of fact, drill-press feeds generally require closed hydraulic circuits and variable-displacement pumps.

If these conditions are not met, the results will usually be unsatisfactory. If a constant-displacement pump is used with a choked bypass to reduce the flow into the feeding cylinder to a required feed rate, the following troubles are encountered:

(*a*) A large drill will feed slower than a small one. Several drills will feed slower than one drill. Still more important, after the drills are dull they will feed very much slower than when sharp, at which time the feed rate was adjusted.

Hence the choke valve must be reset for every change in condition. When tried in practice, this is usually unsatisfactory except for very light drilling, or possibly in some cases for drilling wood.

(*b*) *Overheating.* The oil bypassed under pressure during the feed is continually circulated by the gear pump against the full pressure of the relief valve as indicated in the figure. As the gear pump is usually made very large to provide displacement for a rapid traverse movement many times as fast as the feeding movement, almost the entire energy of this large gear pump is continuously converted into heat during the feeding operation. This overheats the oil, generates gas, and makes the feed irregular. In some cases use of the highest possible grade of lubricating oil will reduce these ill effects.

(*c*) Rate of feed cannot even be approximated except by trial.

(*d*) Drills jump ahead excessively when breaking through.

### Flexibility, Extreme Feeding Force, and Durability of Hydraulic Feeds

The most obvious peculiarity of hydraulic feeds as now available is their flexibility. Any rate of feed may be selected and the effect proved on the work. Designers of single-purpose machines do not have to assume feed rates in advance. The feeds given on production tickets may be tried under shop conditions, and increased or decreased to get the best results. Experience shows that the effects of hydraulic feed cannot be predicted by records from mechanical feeds. The essential peculiarities pointed out in the paragraphs on Inherent Characteristics suggest that hydraulic feeding is an art in itself, and should be so treated. Some users report that a given gang of drills may be pushed twice as fast with the oil feed as with mechanical feed. The records of feeds and speeds made with geared machines are not reliable guides for oil-driven machines. The most conspicuous example of the error of relying on traditional practice is the increase during the past few years in broaching speeds from 4 to 5 ft. per min. up to 12 to 30 ft. per min. This performance has been well known in the trade for four years, and during that time many special milling machines have been equipped with Oilgear feed. Yet most makers of standard milling machines doubted whether anything of importance was to be gained by hydraulic feed, until one prominent builder showed a machine doing a heavy form-milling job with a feed of 10 in. per min., when the same builder's best geared feed had only been able to feed the same job at $2^{1}/_{2}$ in. per min. In an example like this the increase is probably due in part to other factors than the hydraulic feed. But the builders of the machine referred to know of no way to get such a high feed rate except by hydraulic pressure. And they state that their cutters stand up better when fed by oil pressure.

*Extreme Feeding Forces.* A car-wheel boring machine has recently been built using four variable-delivery pumps each having a capacity of 3060 cu. in. per min. at 1000 lb. per sq. in. pressure. Two pumps are used for chucking the car wheels, and two for feeding two boring heads. The feed cylinders are 9 in. bore, giving an available feeding force up to 60,000 lb. on each carriage. The usual force is about 20,000 lb. These feeding pumps are shown in Fig. 4. The maximum rapid-traverse speed is about 100 in. per min.

Another example showing the adaptability to very high feeding forces is a machine for facing the ends of built-up structural columns. The cut is not fed across the end of the column, but a faceplate carries radially placed cutting blades, which are fed against the end of the column. The machines already equipped have one 9-in. feeding cylinder, driven by a hand-controlled pump. The minimum feed required is 0.05 in. per min. The feeding force specified was only 20,000 lb. and the 9-in. cylinder was used to make possible the extremely slow rate of feed (see earlier paragraph on slip).

After reporting very satisfactory results, the makers are now specifying a machine to be fed by two 9 in. cylinders in parallel with a single pump, to give a total feeding force of 100,000 lb.

The design in this case is simple in the extreme. Two simple cylinders with abutments to support them on the baseplate, and with piston rods attached to the carriage, a standard pump costing about $400, and a few pipes complete the outfit.

*Durability.* A most significant advantage of hydraulic over mechanical feeds is their indifference to heavy work. A hydraulic outfit will deliver its maximum feeding force day after day for long periods without strain or perceptible wear. Breakage is almost unknown.

### Hydraulic Feeding Units and Oil Circuits

(*a*) Fig. 5 shows a hand-controlled feeding pump *A* with its two pipe connections leading to the two ends of the feed cylinder or press cylinder *B*. At the high points of the pipe lines are automatic air drains *C* with drain pipe back to oilpot of pump.

Fig. 6 shows the pump removed from its oilpot, and with cover off. Control handle *E* operates stroke-changing cam *G* through a train of gears *F*. Cam *G* rolls against a fixed roller *H*, and is held against roller by a light spring and a small hydraulic plunger not shown.

This is the simplest feed-control system, and the automatic pump and circuits shown below are developed around it. This unit comprises two separate pumps; a variable-delivery pump on the upper side of the baseplate, and a large gear pump on the lower side. The latter pump is employed to furnish a large flow of oil for rapid traverse movements.

(*b*) Fig. 7 shows the simplest valve-controlled pump arranged for automatic control. The unit comprises a variable-delivery pump with a slightly larger gear pump to supercharge it. But the flow from the gear pump is not used for rapid traverse, as in Par. (*a*) above.

It has one rapid traverse movement and one adjustable feed in either direction. The control-valve stem *A* has five positions, and is operated from cam plates attached to the table or tool head, as indicated in Fig. 8. This valve operates to control the flow from the variable pump to the feed cylinder, and also controls the admission of pressure from the gear-pump circuit to change the stroke of the variable pump from full stroke for rapid traverse to the preadjusted full stroke.

When very long table strokes are required as in some grinders, or when the table movement is rotary as in some milling machines, it is desirable to use a rotary motor in place of the feed cylinder. Such a motor is shown in Figs. 9 and 10. Its case is about 13 in. diameter. Its capacity in horsepower and in torque is given in the caption of Fig. 9.

The working parts of such a motor are identical with those of the corresponding pump.

Figs. 11 and 12 show respectively the front and rear views of a semi-automatic press for pressing the brake spiders on the ends of a rear-axle housing. The housing is accurately located and held by expanding jaws *A*, Fig. 11, which are operated by the cylinder *B*, Fig. 12. This cylinder must operate through its full clamping stroke before the main pressing cylinder *E* begins its stroke; a requirement which is met by the spring resistance valves *C* and *D* in the pipe leading from the pump to the two ends of the main cylinder. The branch pipes leading to the clamping cylinder have no resistance valves, and hence the clamping cylinder operates first in both forward and return strokes.

The spring-resistance valves referred to are shown in Fig. 15. These valves oppose a definite resistance to the passage of the oil in one direction, and permit free passage in the opposite direction. The valves may be either adjustable or non-adjustable.

### Conclusion

In this paper the author has only aimed to make an outline sketch showing the trend and progress to date of this development. The changes in machine-tool design which have actually come about in the past five years seem sufficient to suggest that every machine-tool designer should now be studying the new hydraulic engineering, as he has learned in the past to study electrical engineering. When a large number of designers in the machine-tool field are actively considering the possibilities of the hydraulic solution of every problem as compared with the possibilities of the electrical and of the mechanical solutions, the true field of the hydraulic method will be rapidly defined, to the great benefit of all builders and users of machine tools.

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# Hydraulics and Modern Machine-Tool Design

By WALDO J. GUILD,[1] WORCESTER, MASS.

*After showing that incompressible fluids have advantages over air for machine-tool drive and operation, the author shows how the pressure and volume of the pumping unit are determined by the energy required of the device in a unit time, and passes on to a study of the control devices for regulating the volume of fluid delivered to the driven unit by the throttle valve and bypass valve. Applications of hydraulics to several types of machine tools are then described, with brief comments on the valves employed and on air accumulation in the oil lines.*

HYDRAULIC pressure has been in use for many years in the mechanical trades to obtain movement in its various forms, as can be readily seen in hydraulic presses, testing machines, saw tables in the lumber industry, etc.

Compressed air has also been used to a large extent in the operation of chucking devices, drills, hammers, in the movement of slides from one position to another against stops, etc.; and this development is a very logical one, owing to the extreme flexibility of the application of air for the remote control of distant or moving parts, to its automatic adjustment of pressures at whatever position the mechanism is stopped, and to the ease of employment of high pressures with the minimum of manual labor, all of which make this development a logical parallel to the use of hydraulic pressure.

However, the compressibility of the air itself has defeated all attempts to obtain uniform movement of slides by air. This condition is caused by the necessity of building up pressure to overcome the static friction at the start of the movement, thereby creating an uneven or jerky motion which causes the slide to jump forward until the pressure equals the friction plus the load on the slide.

This uneven motion has caused engineers to turn to incompressible mediums such as water, mercury, or oil, particularly to oil on account of its lubricating qualities, and it has been proved that as long as air is kept out of the system, it is a very efficient means of transmitting a steady flow of power.

### How Hydraulic Power May Be Applied to Machines

First, let us consider how this power may be applied. Any mechanical movement, reciprocative or rotative, that is to be obtained hydraulically can be figured to require a certain maximum amount of energy in a given interval of time, as, for example, inch-pounds per minute. Hydraulically this means pressure per square inch times the area in square inches of the surface on which this pressure is impressed, times the travel of the said surface in inches per minute.

This reduces, of course, to pressure per square inch times the displacement in cubic inches per minute, a direct indication of the capacity of the pumping unit required, subject to correction for losses by friction in pipe lines, by leakage, etc.

Having determined the pressure and volume required in our pumping unit to satisfy the maximum requirements of our mechanisms, let us see how we may control this mechanism from rest to its maximum speed; for, aside from its simplicity of application as a transmitter of power, the most outstanding advantage of this hydraulic transmission of power is in its sensitive and easy control of the speed of the driven mechanism.

If we pass the entire output of our pumping unit through our driven unit, the speed of this driven unit may be regulated by controlling the volume delivered by the pumping unit by varying either the latter's speed or its displacement. This constitutes a very efficient means of control, limited only by the mechanism involved to accomplish the result.

Speed control may also be obtained by means of a throttling connection between the two units. If this throttle is closed, the flow of fluid will not pass to the driven unit, and therefore the driven unit will remain at rest or stop if it is in motion. The output of the pumping unit in excess of momentary requirements must be taken care of by a bypassing relief valve set to open at slightly above the maximum pressure needed for maximum requirements. In other words, the pumping unit becomes a nominally constant-pressure unit as well as a constant-volume unit. Truly, it imposes a constant load on the factory power system, but matched against this is its simplicity and general utility. The pumping unit becomes a common source of supply from which a number of various mechanisms may be operated, governed by their individual controls, up to the limit of its own capacity. The relief valve takes care of the excess volume and maintains full pressure on all of the lines at all times.

### Examples of Application of Hydraulic Pressure in Machine Tools

The following outline of several different applications of hydraulic engineering to machine tools will give a brief idea of what is being accomplished in this field.

[1] Chief Engineer, The Heald Machine Company.

Internal-grinding-machine tables are being reciprocated at high speeds with practically no shock at reversals. This is accomplished by using a double-acting-cylinder unit, to drive the table in either direction, controlled for reversing by a four-way valve which connects one end of cylinder to the pressure line and the other end to the exhaust line in one position of the valve, and reverses these connections in its other position. Various types of valves are used, some of the piston type, some of the disk type, and still others of the taper or stop-cock type. This reversing valve is operated by dogs on the table, adjustable for various lengths of stroke and relative position of the stroke to other units. Reversal of the valve by the dogs at each end of the stroke may be wholly by mechanical actuation, or may be accomplished through the actuation of a supplementary valve or valves which in turn actuate the main valve hydraulically. To obtain reversals at high speed, oil dashpots are generally employed in the reversing mechanism to impede its action. However, the use of a relief valve on the main oil supply automatically prevents the rapidly moving table from being at any time imposed against an incompressible body of oil in a closed chamber.

As stated, previously, air must be kept out of the oil system to insure smooth motion. This means tight joints in the pipe lines, especially on the suction side of the pumping unit. At best, however, some air will be picked up by the oil, and must be allowed to escape. This may be done by the occasional opening of pet cocks at the highest points in the system, or will be done automatically if provision is made to keep the oil in motion at the highest point, thereby carrying the air with the oil back to the reservoir tank. Sharp turns in the pipe lines should be avoided, if possible, to reduce friction. Eddy pockets should be avoided as these tend to separate the air which the oil may be carrying in solution.

These grinding machines also gain in speed control by the use of oil transmission of power. By the use of suitable throttle valves and bypass valves, four changes of table speeds are employed during the grinding of one work piece: a rough-grinding speed, a wheel-dressing speed, a finish-grinding speed, and a fast speed for separation of wheel and work to allow room for chucking. The three first named are all adjustable independently.

Oil pressure is also made use of on machines of this type, for the operation of chucking devices, for the opening and closing of chuck guards, for the actuation of diamond dressing tools, etc.

On other types of grinding machines, oil pressure is used to obtain feed of the wheel to the work, either by increments or continuously, during the grinding operation. Wheels are rapidly advanced to and withdrawn from grinding position, as in the grinding of crankshafts. These crankshafts are now being clamped by hydraulic pressure with the mechanism interlocked so as to prevent any grinding being started before the clamps are in proper position.

Wheels are being carried across the work surface at slow speed in one direction and retracted in the opposite direction at high speed, by interposing a valve which will throttle the oil supply when passing through in one direction and which will open as the direction of oil is reversed—a modified check valve. This valve of course is placed between the main reversing valve and one end of the cylinder.

Indexing mechanisms are being operated and locked by hydraulic pressure on various types of machine tools.

Broaches are being pulled through by hydraulic-cylinder units.

Drills and cutters are being held into their cut at a uniform pressure by hydraulic means, with an automatic withdrawal at the completion of the operation.

It will thus be seen that the use of hydraulic pressure on different machine tools and also for different movements in any one machine tool is of great value in eliminating complicated mechanisms with their attendant strains and bearing friction.

Hydraulic pressure is rapidly being applied to all types of machine tools and fixtures, and its uses are practically unlimited as it remains only necessary to solve the problem of the proper method or system of application.

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# Hydraulic Feeding Mechanism for Milling Machines

By SOL. EINSTEIN[1] AND HANS ERNST,[2] CINCINNATI, OHIO

*After giving a brief history of the development of power-driven feeding mechanisms for milling machines generally, the authors describe a hydraulic system which they believe meets the conflicting requirements which a power-driven feeding device on milling machines should satisfy. The operating characteristics of a hydraulic feeding device are stated and the various circuits such as the feeding, rapid traverse, etc., are described. The purpose of the differential pressure-control valve is stated, and the device illustrated and described. By lowering the idle pressure as compared with that required by the simple relief-valve system and by holding the pressure at all times to the level required for the cut taken, this device increases the cutting capacity of the machine and its mechanical efficiency. At the same time it reduces the variation in back pressure under intermittent cutting, and consequently produces a smoother table movement.*

THE development of power-driven feeding mechanisms on milling machines has proceeded along lines similar to the development of other machine tools.

The first milling machines built some hundred or more years ago had no power-driven feeding mechanism at all. About the middle of the last century the so-called Lincoln-type milling machines were introduced, and on these the table-feeding mechanism was driven by means of a belt and multiple-step cone pulleys, thus providing a variable feeding rate. Structural limitations of pulley diameters and belt widths resulted in their restriction to relatively light cuts and correspondingly slow feed rates. The rate of table traverse was a function of the number of revolutions per minute of the spindle, since one cone pulley was placed on the spindle itself and the other upon the feed driving shaft.

Toward the end of the last century and the early part of the present century milling machines with positively driven feed-change mechanism began to make their appearance, and with this construction faster feed and heavier cuts became possible. The disadvantage of the construction then used, however, was that the feed transmission was still driven from the spindle. Thus when the spindle rotated at slow speed the rate of feed in inches per minute was slow even when the fastest feed of the mechanism was used, while when the spindle was running fast an exceedingly high table travel resulted. This was frequently too high for practical use, even when the slowest feed rate was employed.

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[2] Research Engineer, Cincinnati Milling Machine Co.

To overcome this difficulty a drive of the feed mechanism entirely independent of the rotation of the spindle was developed, thus providing feed rates in inches per minute.

With this construction the spindle and feed mechanism were driven from the same source by independent belts, and whenever the spindle-driving belt slipped, an accident resulted.

With the advent of the single-pulley milling machine with self-contained speed-change mechanism the feed transmission was driven directly from the pulley shaft. Feed rates in inches per minute and independent of the spindle speed were

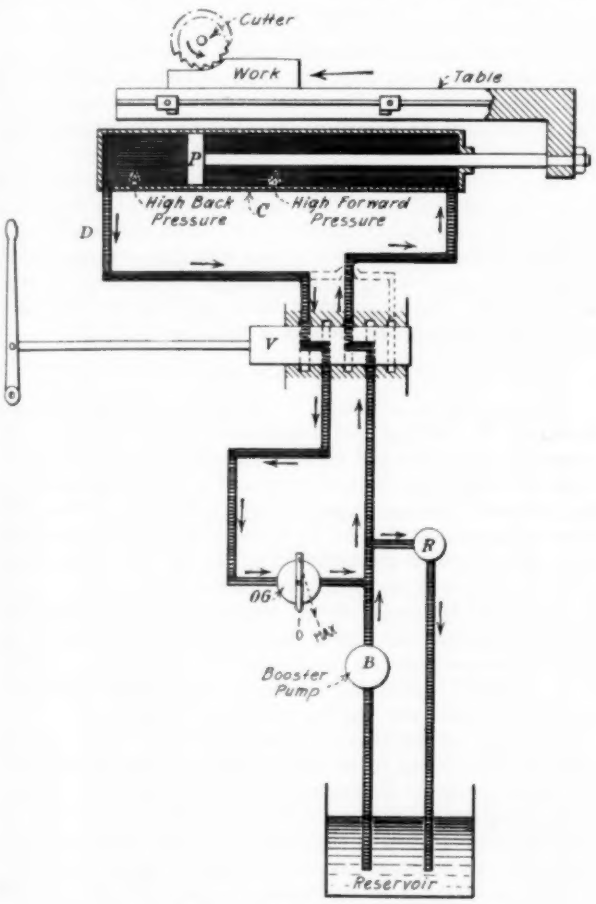



Fig. 1 Feeding Circuit

provided, and at the same time the possibility of a wreck as indicated above was avoided.

At the present time the rates of traverse provided on milling-machine tables vary through a wide range. This is due not only to the great variety of materials milled but also to the great variety of diameters and types of cutters used. Consequently we find many milling machines with a feed range of from $^1/_2$ in. to 30 in. per min. (i.e., a ratio of 60 to 1).

To cover such a large range with a mechanical feed-change mechanism naturally requires a large number of gears, as in order that the most economical feed rate may be used for each individual job it is essential that the gaps between successive rates be not too great. As usually arranged, the mechanism provides a feed rate advancing in a geometric progression, and even an increment of 20 or 25 per cent might not give the most economical feed rate.

It is therefore desirable to have as large a number of feed changes and as close a spacing as can possibly be provided.

Frequently the amount of metal to be removed on various sections of the piece varies considerably. The amount to be removed at one place may be 10 cu. in. per min. and at another place only 3 cu. in. per min. For production work it is impracticable to manually change the rate of feed during the cutting operation in order to utilize as nearly as possible the maximum capacity of the machine. It is, however, very desirable that such an automatic change of feed rate shall be obtained for maximum production.

In other classes of work it is desirable that when the cutter enters the work the feed rate shall be slow, so that the work will not be lifted out of the fixture or vise. Later the feed rate may be materially increased, and thus the cutting time of the piece reduced.

On work where feeding against a shoulder or into solid metal is required, automatic decrease of the feed rate is very desirable, thus increasing the production and at the same time raising the grade of finish.

These are some of the problems which up to this time have not been satisfactorily solved in production milling.

Frictional feed devices of course provide just the conditions desired but lack positiveness and durability. Mechanical devices give positive feed but lack flexibility.

The hydraulic system described below as embodied in the Cincinnati Milling Machine Company's "Giant Hydromatic" fully meets these conflicting requirements.

## General Characteristics

In the application of hydraulics to the reciprocation of a milling-machine table the following operating characteristics must be provided:

1 Reciprocation in either direction at normal feeding rates
2 Reciprocation in either direction at rapid traverse rates
3 Positive control of feeding movement regardless of the direction or amount of the resultant cutting force
4 A locked condition of the table when in the stopped position, thus rendering it incapable of movement under the action of the cutter
5 The ability for accurate reversal of the table under any cutting condition
6 A readily controlled acceleration or deceleration of the feed rate during a cut
7 Economical operation.

Items 3, 4, and 5 are particularly necessary whenever the resultant cutting force may lie in the same general direction as the normal feeding movement. This condition frequently occurs in face milling when the arrangement of the work surface is such that it engages with the cutter on the lower portion only. It also occurs in certain classes of slab-milling and slot-milling work, where a downward movement of the cutter upon the work has been found to possess marked operating advantages.

The above operating characteristics have been obtained in the present instance by the use of a special combination of pumps and auxiliary devices arranged to provide a locked control system; this system being the outcome of a great deal of experimental work with a considerable variety of circuits.

## The Feeding Circuit

Fig. 1 shows in simple diagrammatic form the arrangement of the elements involved in the feeding circuit only. $C$ is a cylinder securely bolted to the bed and carrying a sliding piston $P$ connected to the table by a substantial piston rod. $V$ is a reversing valve; $OG$ an Oilgear variable-displacement pump, and $B$ a small high-pressure booster pump coöperating with the latter to produce a continued forward pressure upon the piston $P$,

the amount of this pressure being determined by the setting of the relief valve *R*.

The space within the cylinder on both sides of the piston is at all times completely filled with oil, consequently, in order that the piston may actually be moved in a given direction by means of the forward pressure, it is necessary that the oil on the other side may be able to escape.

If no escape is permitted there will be no movement of the piston; if some escape is permitted then the piston will advance just as fast as the escaping oil will allow it, and with a positively controlled escapement the rate of advance is virtually independent of the amount of forward pressure applied.

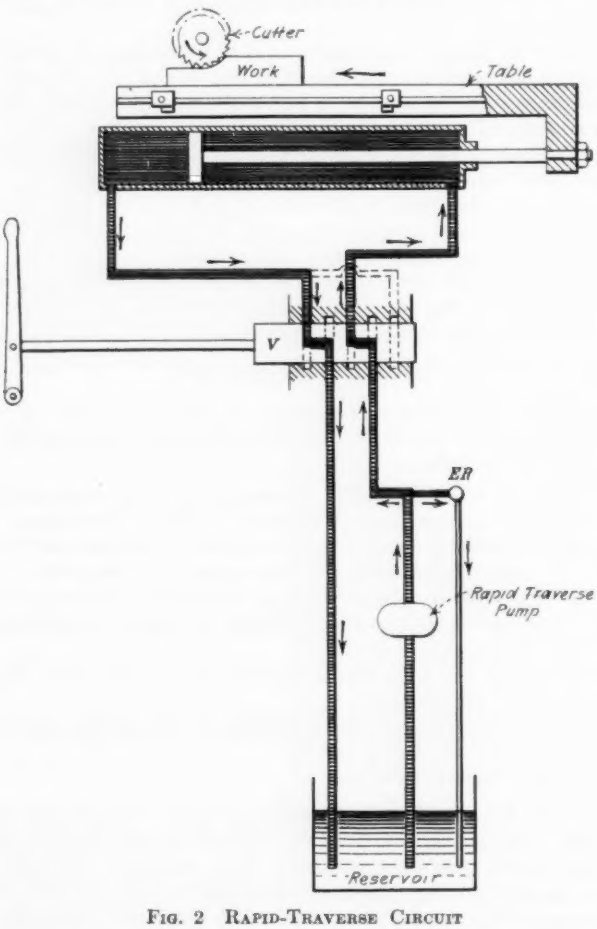



Fig. 2 Rapid-Traverse Circuit

From Fig. 1 it is evident that the only avenue of escape for the oil from the rear end of the cylinder is by way of the pipe *D* through the reversing valve and thence through the Oilgear pump. Consequently, the quantity of oil permitted to escape from the cylinder is definitely fixed by the displacement of the Oilgear pump. As the displacement of this pump may be varied at will from zero to maximum, it is obvious that in this way the forward rate of the table may likewise be readily varied from zero to maximum. Furthermore, in contradistinction to ordinary practice the feed rate is determined not by the amount of oil fed to the cylinder, but by the amount permitted to escape from the discharge end. In this way a high back pressure is built up to resist the movement of the piston, thus providing a constantly receding restraint.

The amount of this back pressure is not constant but varies with the direction and amount of the resultant cutting force. In the case of an upward cut (i.e., *against* the direction of the feed) the back pressure is approximately equal to the forward hydraulic pressure minus the horizontal component of the cutting force, whereas in the case of a downward cut (i.e., *with* the direction of the feed) the back pressure is approximately equal to the forward hydraulic pressure plus the horizontal component of the cutting force. The exact figure in each case is dependent also upon the amount of the frictional resistance encountered by the table, and upon the ratio of the effective areas of the two sides of the piston.

### Rapid Traverse

The circuit described above pertains to a movement of the table at feeding rates only. In order to provide in addition a high table speed for rapid approach to the work and rapid return, use is made of an auxiliary, large-volume, low-pressure gear pump.

Fig. 2 shows in diagrammatic form the arrangement of the rapid-traverse circuit, and from this it is evident that operation of the reversing valve to right or left causes an alternate connection of the opposite ends of the cylinder to pump and to reservoir, thus providing a rapid traverse of the table in either direction. An emergency relief valve *ER* is provided to safeguard the system in the event of a table jam.

### Combined Circuit

For the sake of simplicity in the foregoing paragraphs and sketches, the feeding and rapid-traverse circuits have been separately described and shown. In actual practice both circuits are interconnected and operated by a common control or selector valve arranged to provide both a reversal of table movement and a change of speed from feed rate to rapid traverse, or vice versa. This is accomplished by the use of a valve having both reciprocatory and oscillatory motion.

The entire hydraulic circuit, together with the effects produced by successively placing the selector valve in each of its four operating positions, is shown diagrammatically in Figs. 3, 4, 5, and 6. An auxiliary valve to start and stop the table movement under any condition is shown at *S*.

Inspection of the above diagrams will show that when the selector valve is set to provide a rapid traverse movement of the table the entire feeding system is short-circuited, and similarly, when set to provide a feeding movement of the table the rapid-traverse system is short-circuited; thus either system is independently available at will for table reciprocation.

A check valve *H* in the rapid-traverse-pump discharge line provides a means for preventing a reversal of flow in this line, and thus permits a rapid return movement of the table even when in the middle of a heavy downward cut. Without this valve the horizontal force imparted by the cutter to the table in the direction of its feeding movement would be sufficient to overcome the relatively low rapid-return pressure, thus reversing the flow in this line and opening the emergency valve *ER*. Such an action would permit a rapid escape of the back-pressure oil, with a consequent jamming of the work under the cutter.

By the provision of the check valve *H*, this reversal of flow is prevented and the cutter is permitted to properly clear itself before the initiation of the return movement.

### Differential Pressure-Control Valve

In the foregoing description of the feeding circuit the forward pressure has been assumed to be maintained at a constant value by the relief valve *R*. In actual practice, however, this is not the case.

In order to obtain economical operation and also to maintain a steady table movement, it is desirable that the forward pressure

be not constant but be automatically adjusted to meet the various operating conditions. This is accomplished by the use of a special differential control valve (D.C.V.—Fig. 4) which takes the place of the plain relief valve shown at *R* in Fig. 1.

As previously described, the back pressure on the piston under all conditions is a function both of the forward hydraulic pressure and of the horizontal component of the cutting force. For the simple circuit shown in Fig. 1 (where the forward pressure is maintained at a constant value) the variation in back pressure due to changes in direction and amount of the cutting force is approximately as shown in Fig. 7.

With a downward cut the back pressure rises; with an upward cut the back pressure falls. Thus, from the curves shown, it is evident that with a constant forward pressure of 600 lb. per

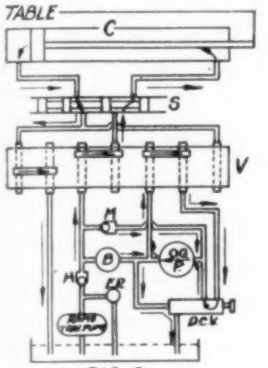



FIG. 3

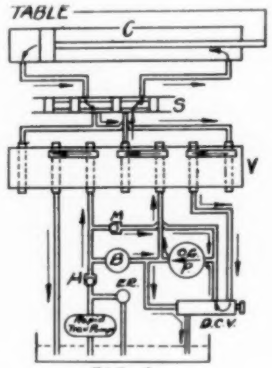



FIG 4

Fig. 3 Rapid Traverse to Left

Fig. 4 Feed to Left

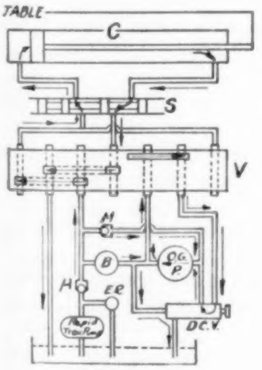



FIG. 5

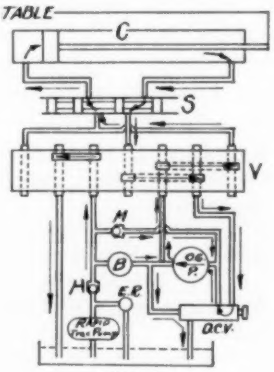



FIG. 6

Fig. 5 Rapid Traverse to Right

Fig. 6 Feed to Right

sq. in. and a cylinder of $4^1/_2$ in. bore the limit of upward cutting is reached with a horizontal cutter load of approximately 8000 lb.; the back pressure under these conditions being reduced to zero. With a downward cut the increase in back pressure is directly proportional to the resultant horizontal force imparted by the cutter to the table, and it will be noted that when this force has a value of 7500 lb. the back pressure (feeding to right) has already reached a value of 1200 lb. per sq. in.

Furthermore, with such a rapid change in back pressure relative to the cutting force, the effect of momentary changes in this force (as caused, for example, by the successive impacts of the cutter teeth, and by the eccentricity of the cutter itself) may become unduly great. It may readily be shown mathematically that owing to the compressibility of the oil these changes in back pressure, with the resulting volumetric variation in the oil itself, may cause an objectionable degree of table movement. This is overcome, as stated above, by the use of the differential valve.

Fig. 8 shows the general arrangement of this differential valve. The end *A* is connected to the forward pressure line, and the plunger end *B* acts in an exactly similar manner to that of the simple relief valve shown in Fig. 7(*a*) to permit the escape of the excess oil supplied by the booster pump. The back-pressure oil returning from the cylinder enters this valve through the inlet port *C* and passes out through the outlet port *D* on its way to the variable-displacement pump. In passing through this valve the back pressure also acts by way of the radial and axial holes *E*, *F*, and *G* upon the enlarged plunger head *H*, thus assisting the forward pressure in its work of moving the plunger against the compression of the spring *J*.

Thus it is obvious that if the back pressure be reduced, the forward pressure must carry a greater proportion of the spring load and thus will be correspondingly increased; whereas, if the back pressure be increased, the forward pressure will correspondingly decrease.

The effective area under the head *H* upon which the back pressure acts is, in the present instance, three times the area of the end *B* acted on by the forward pressure. Thus, for a given change in back pressure, the corresponding change in forward pressure is three times as great.

The relation between forward and back pressures for any resultant force under these conditions is shown in Fig. 9. It will be noted that by the use of the differential valve the capacity of the machine has been tremendously increased. In upward cutting the back pressure does not fall to zero until a cutting force of approximately 15,000 lb. has been reached, yet at this time the forward pressure has not exceeded a satisfactory figure. With a downward cut of 6000 lb. the back pressure is only 400 lb. per sq. in., the forward pressure at this time being reduced to about 50 lb. per sq. in.

Under these conditions the forward pressure has reached the limit set by the natural throttling of the oil through the small orifice *K*, thus no further reduction can take place, and consequently for increased cutter loads in this direction the back pressure will increase at a faster rate. This accounts for the sharp upward break in the back-pressure curve at this point.

In order to safeguard the machine against excessively heavy downward cuts, the upper portion of the differential-valve plunger is provided with a tapering shoulder *L*, which acts under a predetermined limit of pressure to shut off the flow of the back-pressure oil to the variable-displacement pump, in this way tending to reduce or entirely stop the table feed.

In upward cutting, a limit is automatically provided when the back pressure falls to a low value. Under such circumstances a check valve *M*, Figs. 3 to 6, opens to admit a flow of oil from the rapid-traverse-pump discharge line to the variable-displacement-pump intake. This tends to keep the entire system filled with oil under pressure at all times and permits an uninterrupted normal operation of the variable-displacement pump under all operating conditions.

By the use of the differential valve, the idling pressure has been lowered to 300 lb. per sq. in., as compared with at least 600 lb. per sq. in. required by the simple relief-valve system, and at all times the pressure is advanced only to the degree required for the cut taken. Thus the cutting capacity of the machine and its mechanical efficiency have been greatly increased; and furthermore, by virtue of the compensating action provided, the variation in back pressure (and consequent irregularity of table movement) have been reduced to a satisfactory condition. Surging of the valve is prevented by the choking

action of the restricted passage space between the plunger portion *H* and the valve-body bore.

### Practical Application

In the development of this hydraulic feeding system a considerable variety of circuits and devices were experimented with

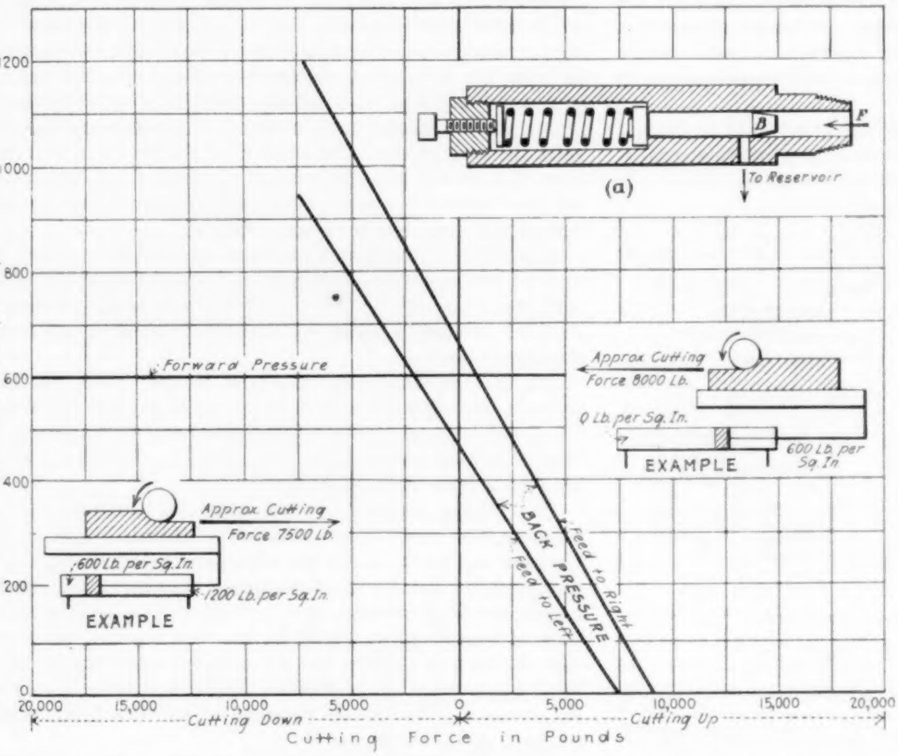



Fig. 7 Approximate Relation Between Forward Pressure, Back Pressure, and Cutter Load with Simple Relief-Valve System

to determine their ability to fully meet production milling conditions.

For this purpose the various experimental elements were arranged as shown in Fig. 10, the pumps being independently driven, and connected with the cylinder and valve members by means of piping. In this way any desired circuit could be arranged and tested under actual milling conditions. The final circuit as described above is the result of this investigation.

In its practical application the system has been reduced to a few relatively simple parts so grouped as to form a compact yet readily accessible hydraulic unit. As shown in Figs. 11 and 12, the elements used comprise the rotor and pendulum of a standard Oilgear pump, a small booster pump of extremely simple construction, a high-grade gear pump, and the necessary control valves. External piping has been practically eliminated, the various interconnections being chiefly made by drilled holes through the various parts. This insures a correct and dependable arrangement of the circuit, and adds greatly to the neatness and reliability of the entire system.

From Figs. 11 and 12 it will be seen that all three pumps together with the control valve and auxiliary mechanisms are compactly arranged in a single casing, an extended lower portion of which forms the oil reservoir. As shown in Fig. 13, this unit is attached to and forms the closing member for the rear portion of the main bed structure of the Cincinnati "Giant Hydromatic" miller, two pipe unions only forming the connection from the unit itself to and from the table cylinder.

This construction renders the entire unit readily removable and furthermore any slight leakage from pumps, valves, etc. is directly returned to reservoir.

### Elimination of Air from System

In any hydraulic system used in the operation of machine tools it is essential that special care be taken to eliminate air from the entire circuit. This is successfully accomplished in the present instance by the provision of an air-drain coil in each cylinder head.

These air drains each consist of a tightly wound coil of about 36 ft. of 0.045-in.-bore copper tubing, one end of which communicates directly with the inside of the cylinder at a point close to the top, and the other end with a pipe leading to reservoir.

As the resistance to the flow of air through these tubes is so much less than that encountered by the oil, a ready escape is provided for any air which may enter the cylinder, while the leakage of oil through the same tubes is an insignificant amount.

### Advantages Gained by the Use of Hydraulic Feed

1 *Flexibility of Feed Control.* The advantages gained by the use of hydraulic feed are as follows:

*a* Any desired feed rate from zero to maximum. As previously stated, this is accomplished merely by the setting of the pendulum of the variable-displacement pump from zero to maximum.

*b* Automatic change of feed rate during cut (if desired), thus providing maximum metal removal.

*c* Any desired cycle of feed and quick traverse in either direction, together with automatic stop or feed change at any point.

*d* Possibility of milling in a given direction until the table encounters a positive stop, then dwelling to allow cutter to clear itself, and after a predetermined short interval of time automatically returning the table at a rapid traverse rate.

*e* Accuracy of trip. Owing to the fact that no clutches or other mechanical devices are employed which may carry varying loads depending on the size of the cut taken, the tripping from feed rate to rapid traverse or vice versa is very accurate. This is assisted by the particular design of valve used, which provides a balanced condition at all times.

Item *b* is particularly valuable in production milling wherever the width of piece to be milled is not uniform throughout its length. Under existing practice it is necessary to limit the feed rate for the entire piece by the proper rate for the widest part, whereas with the hydraulic system a simple cam may be arranged as shown in Fig. 13 to automatically adjust the feed rate to the amount desired for each successive table position.

Figs. 14 and 15 show the benefit derived by the use of this feature on a typical face-milling job. The curves shown were

described by a graphic wattmeter and thus indicate both the instantaneous power required and the length of time taken for the entire piece. With a constant feed rate as in Fig. 14 the maximum power was required for a relatively short space of

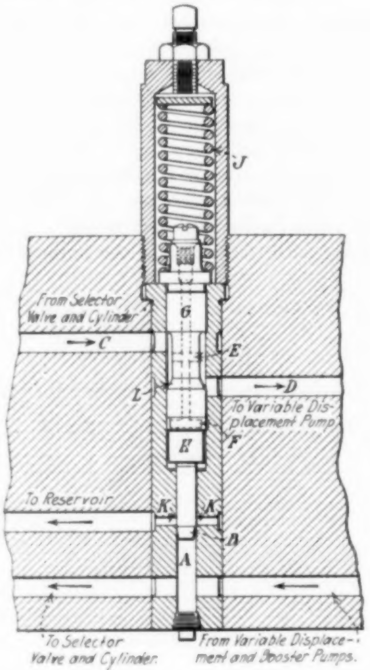



FIG. 8 GENERAL ARRANGEMENT OF DIFFERENTIAL CONTROL VALVE

time, the entire cut taking 137 seconds. On the other hand, with the cam-adjusted feed rate as shown in Fig. 15, this time was reduced to 100 seconds, the maximum power being approximately constant throughout the entire cut.

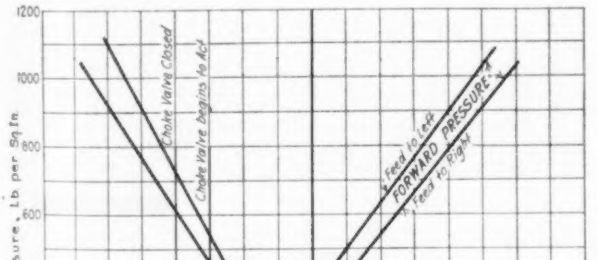



FIG. 9 APPROXIMATE RELATION BETWEEN FORWARD PRESSURE, BACK PRESSURE AND CUTTER LOAD
(With differential valve; ratio 3:1.)

By the use of an auxiliary hydraulic attachment a similar automatic adjustment of feed rate to suit the work can in certain cases be provided, thus eliminating the need for a special cam.

2 *Longer Cutter Life.* In the application of hydraulics to broaches, drilling machines, and other machine tools one of the most outstanding characteristics noticed has been an exceptional

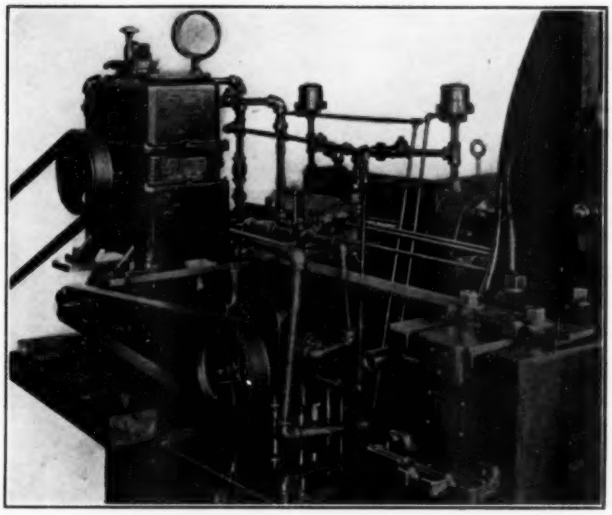


FIG. 10 EXPERIMENTAL HYDRAULIC-FEED UNIT

increase in the life of the tool, and the same effect has been found to exist in the case of the hydraulic-feed milling machine.

For a proper understanding of this phenomenon we must consider in detail the action of a cutting tool during the process of chip formation.

It has been repeatedly shown that the formation of a chip by the action of a tool in its passage through the metal is by no means a continuous or uniform process involving a constant pressure upon the tool. Even when the chip removed is of uniform cross-section, the force normal to the cutting edge varies in a definite cycle with the formation of each successive chip element. It appears, in fact, that with a chip of any practical thickness we have a continued succession of plastic deformation—with a consequent crystal elongation and work hardening—and subsequent shear.

Under practical cutting conditions these load variations occur at exceedingly high rates (probably in the neighborhood of 1000 per second), consequently the actual instantaneous force variations on the cutting tool will be greatly influenced by the character of the mechanism sustaining the work in opposition to the cutter. Where this mechanism is of a mechanical nature, relatively little yield can occur, and consequently the peak loads may rise to a high value. Furthermore, to the extent that any of these members may yield, the energy stored by such yielding is fully returned to the system during the periods of diminishing load. With a hydraulic feed mechanism, on the other hand, owing to the far greater compressibility of the oil, greater yielding can

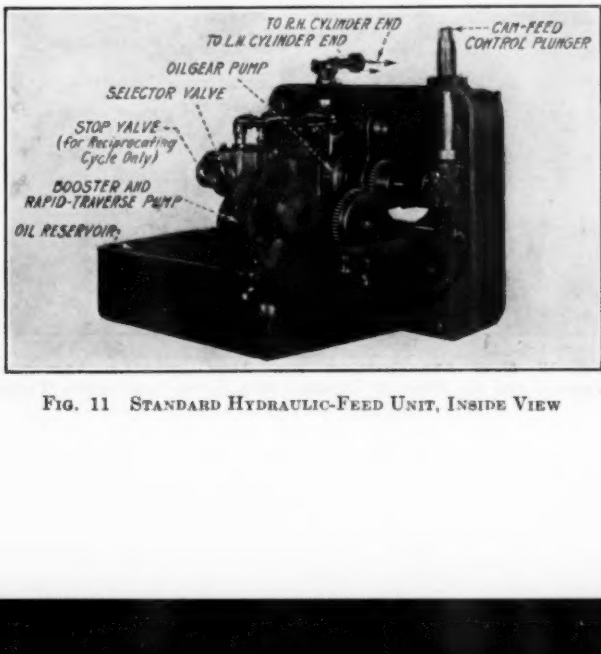



FIG. 11 STANDARD HYDRAULIC-FEED UNIT, INSIDE VIEW

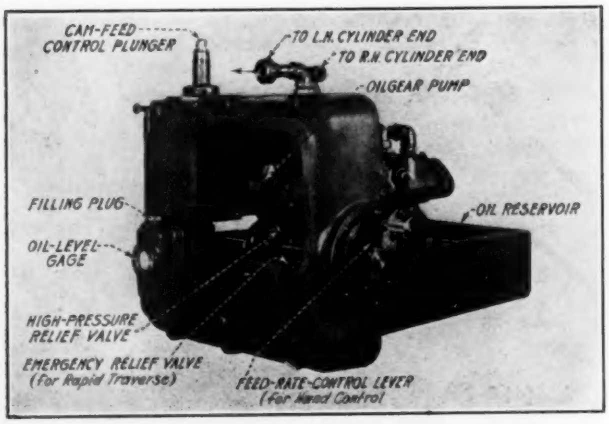



FIG. 12 STANDARD HYDRAULIC-FEED UNIT, OUTSIDE VIEW

take place; consequently the peak loads cannot rise to so high a value. Furthermore, due to the fact that the slight leakage constantly occurring throughout the system is a function of the instantaneous pressure, it is obvious that such momentary increases of pressure as do occur tend to momentarily increase the leakage. Thus in this case there is never a complete return to the system of the energy stored in the yielding members.

The exact effect of the hydraulic feed upon the character of the instantaneous-pressure curve has not yet been definitely determined, but it is apparent that some such action as above described must inevitably take place. An investigation is now under way to obtain exact information in regard to this action, and to the effect of the various factors involved; the instantaneous force variations being analyzed by the use of piezoelectric pressure gages.

In the case of milling we have in addition to these high-frequency force variations a further cyclic variation due to the successive impacts of the cutter teeth upon the work. Even in the case of spiral or helical mills where several teeth are in contact with the work at the same time, the summation of their individual loads cannot be constant. Furthermore a milling cutter is never absolutely concentric, and thus we have an additional cyclic variation of the load per revolution of the cutter. The last two variations, namely, those caused by the tooth

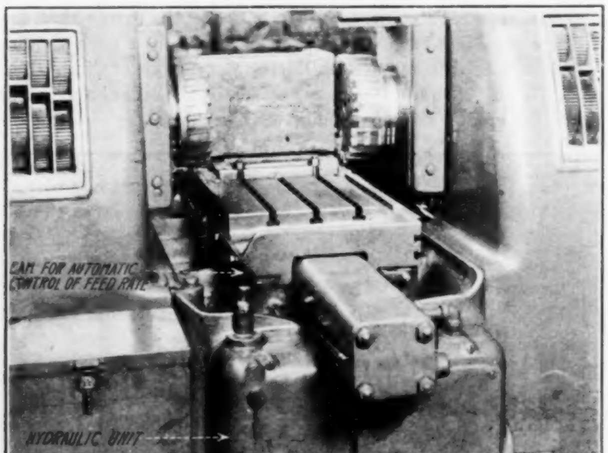
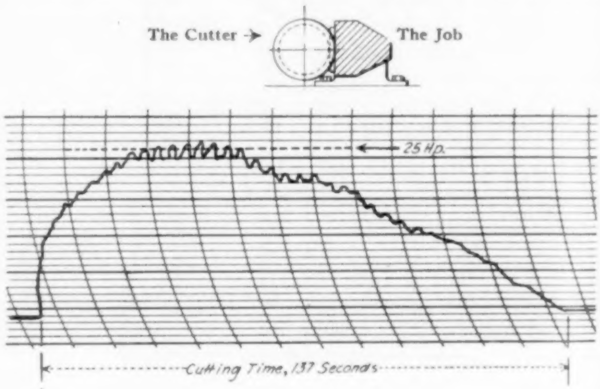



FIG. 13 CAM ARRANGEMENT FOR AUTOMATICALLY ADJUSTING FEED RATE TO AMOUNT DESIRED FOR EACH SUCCESSIVE TABLE POSITION

impacts and by the eccentricity of the cutter, can readily be investigated by the use of a graphic wattmeter.

Fig. 16 is a graphic-wattmeter record expanded to such a degree that both of these variations are clearly visible. Figs. 17 and 18 are wattmeter records of identical cuts taken on machines similar in every respect with the exception that one was arranged with a mechanical feed while the other was arranged with hydraulic feed. The same cutter was used and all precautions were taken to produce identical conditions on both machines. From an inspection of these curves it will readily be seen that the power variation due to cutter eccentricity was very much less in the case of the hydraulic feed. Owing to the depth of the cut taken in this case, and the scale of the chart, the individual tooth impacts are not visible.

Simultaneously with the taking of the power records, records



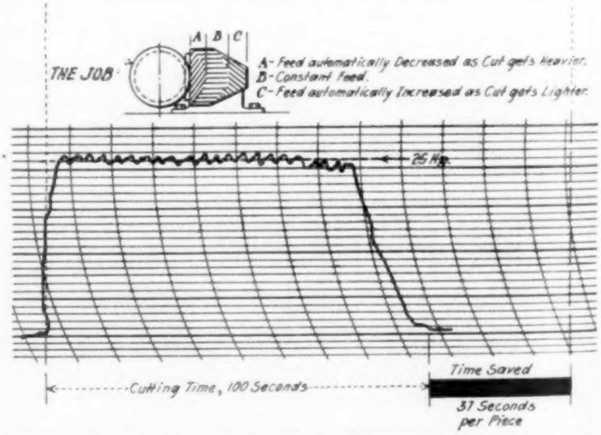




FIG. 14 (ABOVE) POWER CHART FOR CUTTING BY USUAL METHOD WITH CONSTANT FEED RATE

FIG. 15 (BELOW) POWER CHART FOR CUTTING BY NEW METHOD WHERE A CAM-CONTROLLED VARIABLE FEED GIVES CONSTANT METAL REMOVAL FOR ENTIRE JOB

were also made of the actual movement of the milling-machine tables; the curves made by the mechanical and hydraulic machines being respectively shown in Figs. 19 and 20. Close inspection of these curves will show that the mechanically driven table moved at a practically constant rate, while the hydraulically moved table did not move at a constant rate but definitely yielded a measurable amount under each successive tooth impact and for each revolution of the cutter. These curves definitely associate the yielding of the table with the reduction in power variation per revolution of the cutter, and consequently tend to bear out the theory that the increase in cutter life with a hydraulic feed mechanism is directly due to the fact that it does provide a yielding drive in place of the

absolutely constant drive furnished by a mechanical feed.

3 *Efficiency of Metal Removal.* Practical tests covering a wide variety of work have indicated substantially higher efficiency of metal removal per hp. by the use of the hydraulic feed.

The result of this investigation together with detailed data obtained by the investigation on cutter life and chip formation,

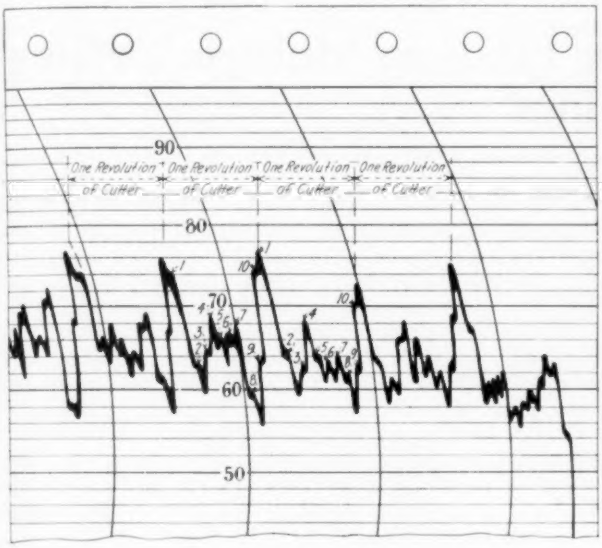



FIG. 16 GRAPHIC-WATTMETER RECORD ENLARGED TO SHOW VARIATIONS CLEARLY

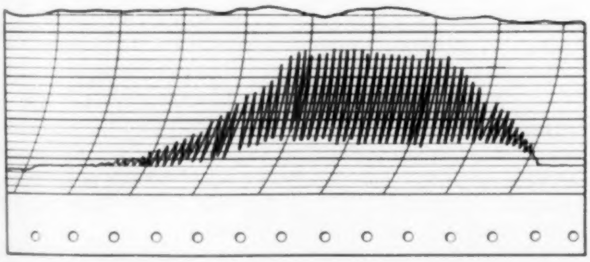


FIG. 17 GRAPHIC-WATTMETER RECORD OF SLOTTING CUT ON MECHANICAL-FEED MILLING MACHINE

(Cutter diam., $6^3/_4$ in.; cutter speed, 32 r.p.m.; depth of slot, $1^3/_4$ in.; width of slot, $^{23}/_{32}$ in.; feed rate, $3^1/_2$ in. per min.)

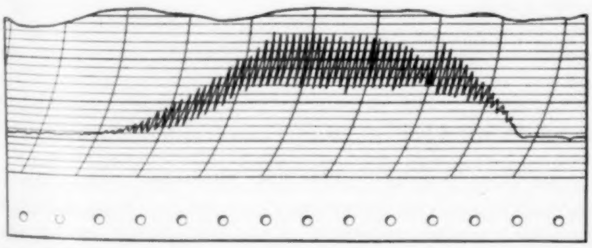


FIG. 18 GRAPHIC-WATTMETER RECORD OF SLOTTING CUT ON HYDRAULIC-FEED MILLING MACHINE

(Cutter diam., $6^3/_4$ in.; cutter speed, 32 r.p.m.; depth of slot $1^3/_4$ in.; width of slot, $^{23}/_{32}$ in.; feed rate, $3^1/_2$ in. per min.)

(when feeding both with and against the cutter), will be made the subject of a subsequent paper.

4 *Safety.* As previously described, the entire feeding transmission is automatically safeguarded against overloading by the action of the various relief and control valves, consequently at no time can a wreck occur.

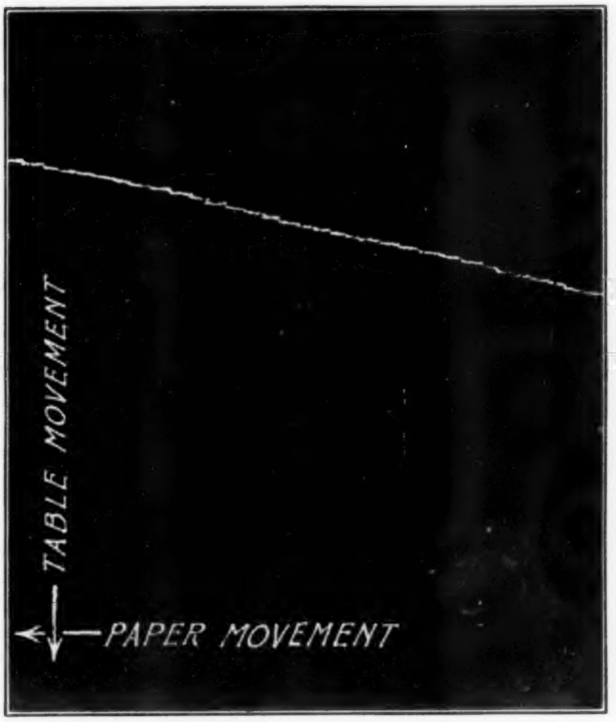



FIG. 19 RECORD OF TABLE MOVEMENT UNDER INTERMITTENT CUT ON MECHANICAL-FEED MILLING MACHINE

During the experimental work which was carried on it frequently happened that the machines and cutters were overloaded to a point where the feed mechanism was stalled, and

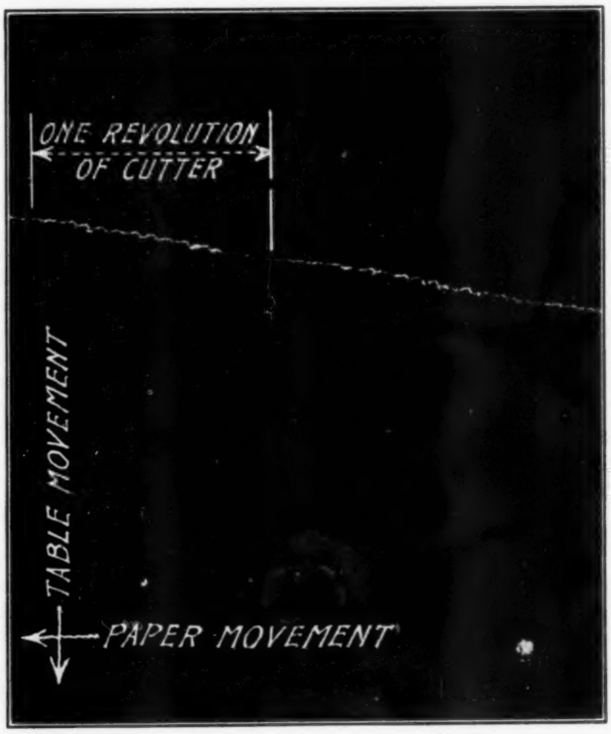



FIG. 20 RECORD OF TABLE MOVEMENT UNDER INTERMITTENT CUT ON HYDRAULIC-FEED MILLING MACHINE

occasionally the work slipped from its proper position. In no case, however, did the machine or cutter suffer any serious damage.

5 *Simplicity.* From an inspection of Figs. 11, 12, and 13, it is obvious that this hydraulic feed mechanism, as a self-contained unit, is far simplier than a corresponding mechanical feed transmission with its numerous shafts, gears, clutches, etc. Auxiliary transmissions are completely avoided, and, as shown above, it provides many valuable features unobtainable with a mechanical feed drive.

# The Development of Hydraulic Feeds on Multiple Drilling Machines

By R. M. GALLOWAY,[1] RICHMOND, IND.

*The author tells first of the three types of hydraulic pumps in general use for feeding machine tools: namely, the gear pump, arranged to operate at pressures up to 250 lb. and capable of delivering a constant volume at a constant pressure; the multiple-piston pump with variable stroke, built to deliver a variable amount of oil at pressures up to 1000 lb.; and a combination of these two arranged to deliver a large volume of oil at 250 lb. pressure from a gear pump and a smaller volume from a variable-delivery piston pump, both pumps being built into the same housing and interlocked as to control.*

*Following this, he relates experiences encountered in adapting hydraulic feeds to multiple-spindle drilling machines, and in the development of smaller machines with less expensive pumps.*

*The success attained led to the development of self-contained units which could be built into designs of special drilling machines, as it was found that a single gear pump could be arranged to supply all the feed cylinders. These have been built into machines having from 2 to 7 units. The paper concludes with a statement of some of the lessons learned during the development.*

MACHINE TOOL manufacturers are just beginning to realize the possibilities in the use of hydraulic means for feeding and traversing the various units of the machines they produce. It is only within the last few years that standard machines have been designed with a hydraulic feeding mechanism, built in as a part of the machine.

About the first tools to be hydraulically operated were broaching machines. The great increase in production and ease of operation of these machines, together with a low maintenance cost, brought the use of hydraulic feeds forcibly before the machine-tool builder and user.

Later grinders and drill presses were hydraulically equipped with equal success in increased production. At present several lathe and chucking-machine manufacturers, and at least one large builder of milling machines, are experimenting along the same line. It is evident from the interest shown in hydraulic feeds, both by manufacturers and users of machine tools, that the time is fast approaching when this type of feed will be in general use on all kind of tools.

### Types of Pumps Used in Feeding Machine Tools

At present there are three types of pumps in general use for feeding machine tools:

1 An accurately made gear pump capable of delivering a constant volume of oil at a constant pressure. These pumps are usually arranged to pump at pressures up to 250 lb. A relief valve is used in connection with this type of pump for maintaining an even pressure.

2 A multiple-piston pump with variable stroke. This type of pump is built to deliver a variable amount of oil at pressures up to 1000 lb.

3 A pump which combines the first and second types and is arranged to deliver a large volume of oil at about 250 lb. pressure from a gear pump, and a smaller volume at a higher pressure from the variable-delivery piston pump. Both pumps are built into one housing and interlocked as to control.

The National Automatic Tool Company started experiments about six years ago with the idea of adapting hydraulic feeds to multiple-spindle drilling machines. The first experiments were carried out using the combination pump manufactured by the Oilgear Company. These experiments were not entirely satisfactory, due partly to the mechanical control of the pump, and partly to the fact that the attempt was made to adapt the hydraulic mechanism to a standard vertical machine designed to use mechanical feeds.

However, the experiment did convince the company that there were great possibilities in the hydraulic feeds if properly applied and controlled; that hydraulic feeds should be applied to machines particularly designed for them, and that these machines should be very rigid and as free from vibration, under working conditions, as possible.

### Types of Machines Designed

With these ideas in mind a vertical multiple-spindle drilling machine was designed, using an Oilgear automatic pump and a $6^1/_8$-in. cylinder. This equipment would furnish a maximum pressure of 24,000 lb. for feeding the drills, with a rapid traverse to and from the work of 80 in. per min.

The mechanical part of the control was arranged so that the operator could set the feeding mechanism to perform any one of its functions, that is, rapid down, either of two rates of feed, rapid up, or stop. Also by means of the same lever the feed could be started and would go through a cycle of operations, automatically stopping at the end of the rapid up movement. The distances traveled at the different rates of feed were controlled by the position of dogs, adjustably mounted on the column of the machine. (See Fig. 1.)

The machine was constructed unusually heavy and rigid to stand the added load of the hydraulic feed and to reduce vibration. Upon being tested it proved entirely satisfactory.

This design has been used with only minor changes during the past two years. Every machine built has shown a decided increase in production with very low maintenance cost as compared to mechanical-feed machines of equal capacity.

A somewhat smaller machine built along similar lines but using a $5^1/_2$-in. instead of a $6^1/_8$-in. cylinder has been equally successful.

The success of these machines led to the development of still smaller machines on which it was desirable, if possible, to use a less expensive pump.

With this in mind, after a careful investigation, it was decided to experiment with a well-built gear pump. The Heald pump was selected, and especially equipped with a 200-lb. relief-

[1] The National Automatic Tool Company.

valve spring. This pump was capable of delivering 15 gal. of oil at 200 lb. pressure, and required approximately 3 hp. to operate.

A machine was wanted for a particular field which would have approximately 7500 lb. feeding pressure. In order to get this feeding pressure with 200 lb. line pressure, it was necessary to resort to the use of two cylinders of 5 in. diameter. In order to avoid interference with the work-holding fixtures the cylinders were mounted near the top of the column, pushing at each side of the head. The two cylinders worked in perfect harmony without noticeable side thrust on the ways. (See Fig. 2.)

The control of the feed on a machine equipped with a constant-pressure, constant-flow pump was very simple.

A slide valve was arranged so that the straight-line motion of the slide connected a supply port with various other ports in turn as the motion progressed. At the same time other ports were connected to a drain line. The valve was operated through

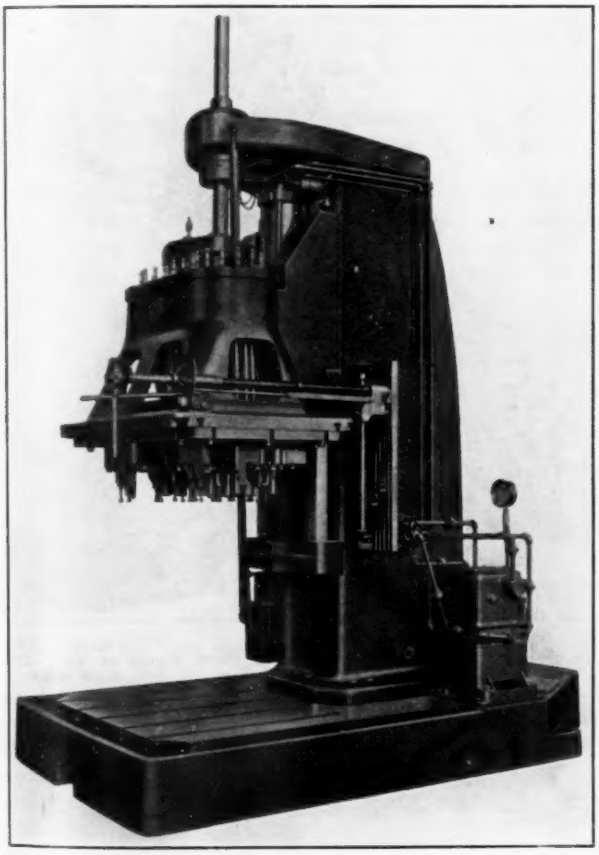


Fig. 1 Vertical Multiple-Spindle Drilling Machine Equipped with Hydraulic Feed

a "load-and-fire" device. This device could be loaded by a hand lever, or by a small oil or air cylinder. It was arranged to discharge or unload by steps or stations, each station causing a rearrangement of the port connections in the valve.

These machines were so well received by the trade that it became necessary to develop a series of machines, for way drilling and for special applications.

Up to that time (1925) special two-, three-, or four-way drilling machines were very expensive to build, because they were usually designed new throughout for each job. The new design required new patterns, and caused foundry and shop delays. It was necessary to bring parts through the shop in lots of one or two. This all led to high cost and to slow delivery of the finished machines.

The expenditure for a special machine of this type was only justified under very high productive requirements, and when the part being operated upon was not apt to be changed. The result was that a very small proportion of the total number of drilling machines built were way machines, most drilling operations being performed on standard vertical machines which could be obtained at a reasonable cost and on short notice, and could be adapted to the changing requirements of the work.

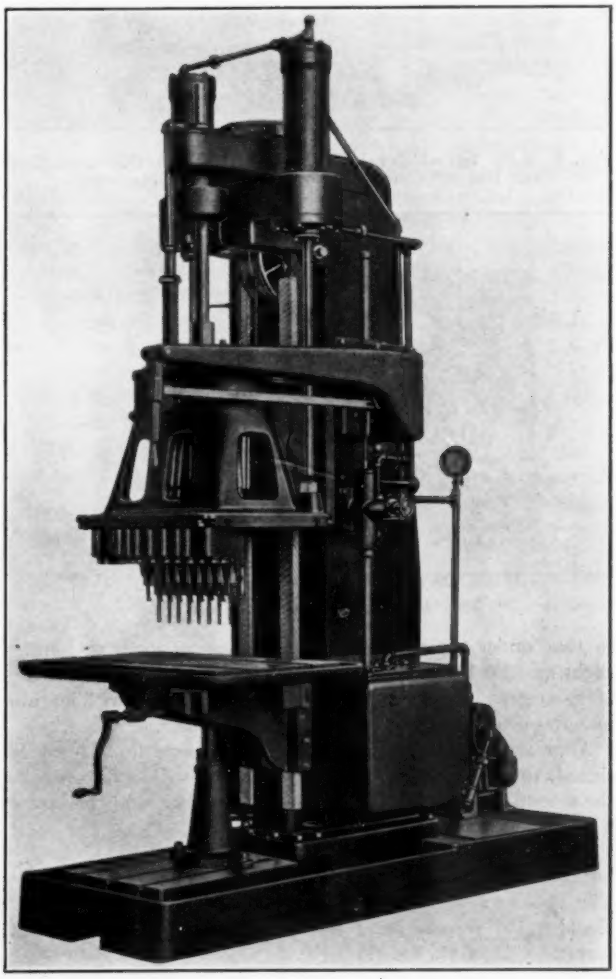


Fig. 2 Smaller Type of Vertical Machine with Two Hydraulic Cylinders

In developing the hydraulic way drilling machines, it was decided to so design a self-contained unit that it could be used, mounted in various positions, to form a way machine, composed of one or more self-contained units arranged on a base, bed, or column, or a combination of these.

### Units Developed for Assembly into Way Drilling Machines

It was desirable to have several sizes of units in order to handle the range of work. It was also important that several units should be operated from one supply pump in order to simplify the machine and keep the cost as low as possible.

Experiments showed that several cylinders could be operated simultaneously by oil supplied by a single gear pump. It was further found that if sufficient oil was being pumped at all times,

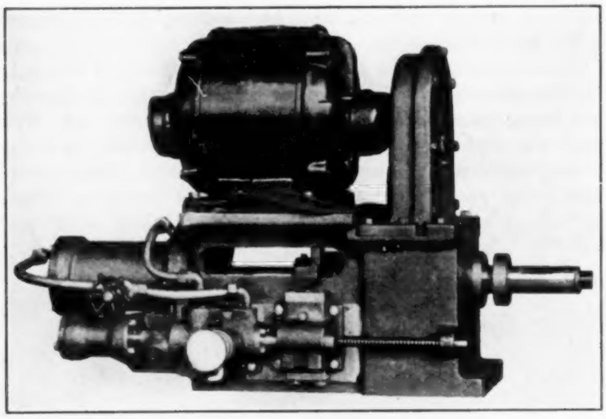


FIG. 3 3-IN. SELF-CONTAINED HYDRAULIC-FEED DRILLING UNIT FOR USE IN CONSTRUCTING WAY DRILLING MACHINES

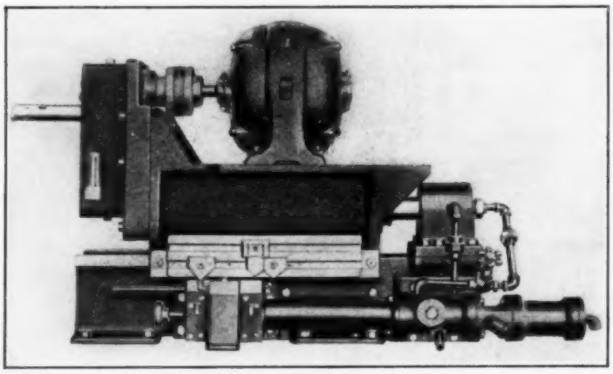


FIG. 4 4-IN. TRAVELING-HEAD UNIT

so that under the worst conditions of usage there was still a slight amount being bypassed through the relief valve, the rate of movement of any cylinder could be changed without any material change in rate of travel on the others.

After the investigation was completed, three units were designed, the smallest having a 3-in. cylinder with a 6-in. stroke, the second a 4-in. cylinder with a 12-in. stroke, and the largest a 6-in. cylinder with a 16-in. stroke.

In the case of the 3-in. unit a cylinder was mounted directly back of a single live spindle. The unit proper remained stationary, the spindle being traversed to the work, fed through it, and returned to a stopping position by the thrust of the piston rod. A motor was mounted on the unit above the cylinder, for rotating the spindle, the desired speed of the spindle being obtained by changing the gears connecting the motor shaft to the spindle. A slide valve, operated by a "load and fire" mechanism, was mounted on the side of the unit for controlling the feed cylinder. (See Fig. 3.)

These units were tried out, and later built up into special machines having from two to seven units. One reservoir and one pump were assembled in each machine. All units were standard and were started—and could be reversed in case of emergency—from a single air valve mounted conveniently for the operator. All units in one of these special machines would start simultaneously, and each had its own length of rapid traverse forward and feed forward, and its own rate of feed in inches per minute. This arrangement made it possible to handle a great variety of work on one machine; that is, one unit could be drilling a $^1/_4$-in. hole, the next unit a $^5/_8$-in. hole, while another could be reaming, and still another counterboring; and all of the units would be operating at the proper speed and feed for the tool being used, and to the correct depth.

The 4-in. unit was designed somewhat differently, being a

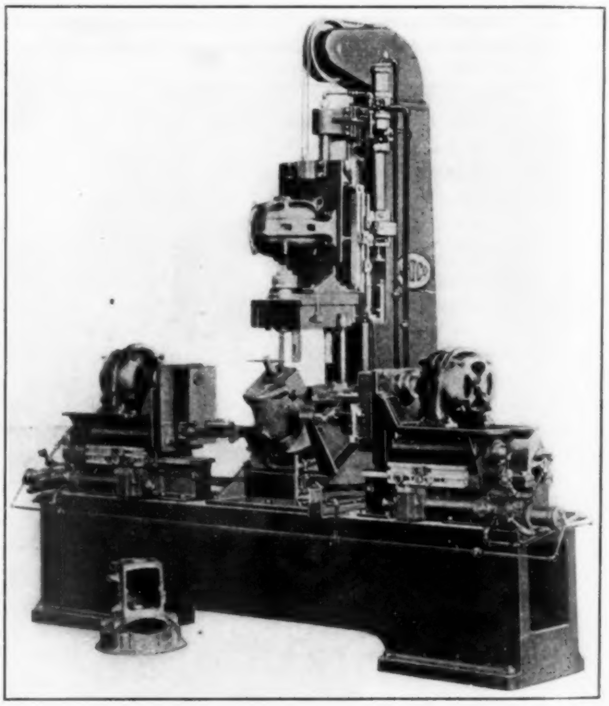


FIG. 5 WAY MACHINE CONSTRUCTED FROM UNITS OF THE TYPE SHOWN IN FIG. 4

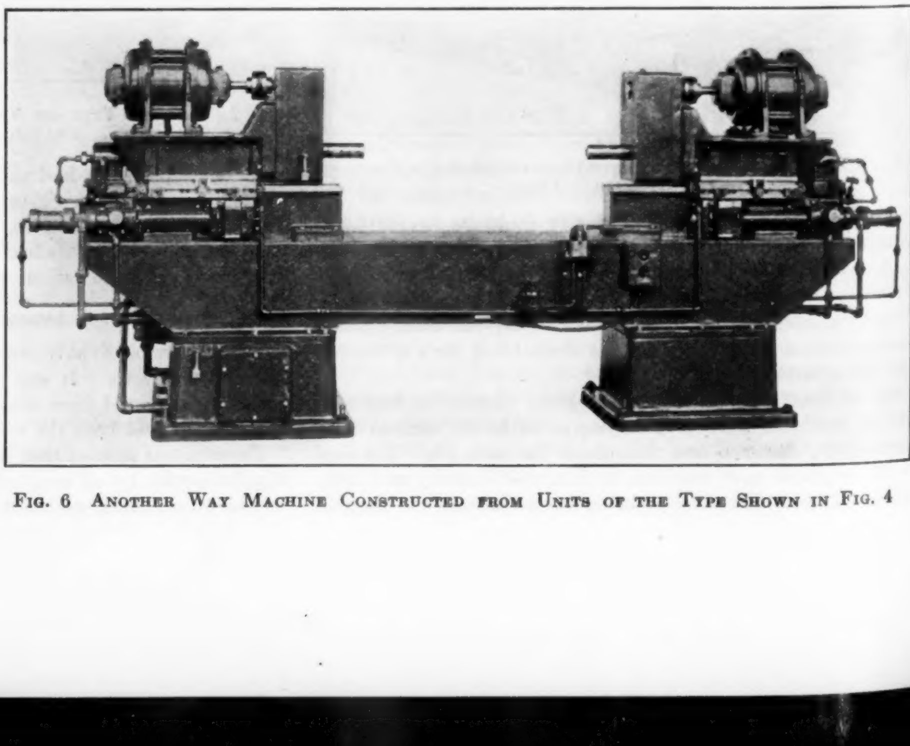


FIG. 6 ANOTHER WAY MACHINE CONSTRUCTED FROM UNITS OF THE TYPE SHOWN IN FIG. 4

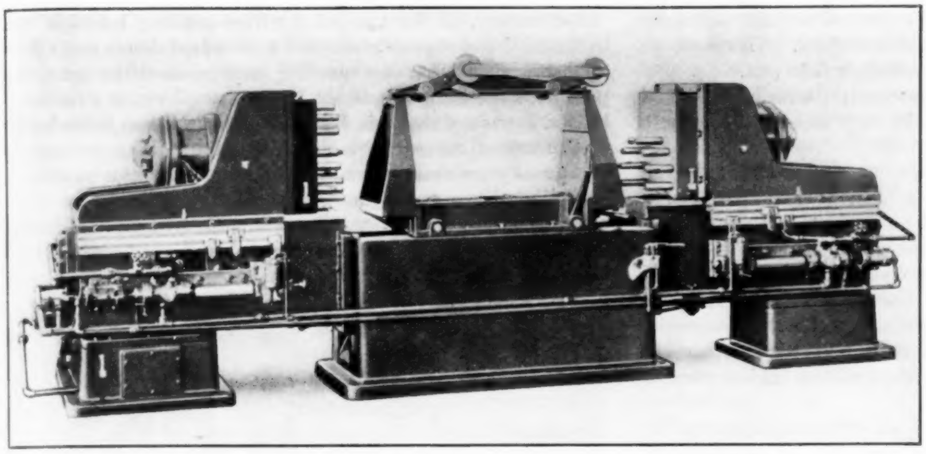


FIG. 7 ONE TYPE OF TWO-WAY MACHINE CONSTRUCTED FROM 6-IN. UNITS

traveling-head unit mounted on ways instead of a traveling-spindle unit. (See Fig. 4.)

In this unit, in order to get a long travel in as compactly as possible, the cylinder was made part of the head and traveled with it, while the piston rod remained stationary. This type of unit was arranged to carry a motor and a "spindle cluster" box, the size of the motor and arrangement of the "spindle cluster" being determined by the work to be done.

Units of this type can be combined into way machines as shown in Figs. 5 and 6.

The 6-in. unit was similar to the 4-in. except that, compactness not being so important in this size, the cylinder was mounted in the bed. The combination of this size of unit into a two-way machine is illustrated in Figs. 7 and 8.

The units are produced in quantity and carried in stock together with several sizes of pumps and tanks.

To build a special machine it is only necessary to build specially the spindle, cluster boxes, and mounting frame. The remainder of the machine is standard.

### Advantages of Unit System

This system has worked out very satisfactorily, both from a delivery and a cost standpoint. The machines have been well received by the trade, and have proved highly productive.

The construction of special machines from standard hydraulic units has made it possible for the manufacturer of moderate quantities of parts to profitably use this type of machine.

In conclusion, it might be well to mention some of the lessons learned during the past two years in the manufacture of hydraulic equipment. Our experience has been that seamless brass tubing in iron-pipe sizes should be used instead of ordinary piping, and that up to 300-lb. pressures, bronze fittings are satisfactory. In the higher pressures heavy-duty steel fittings should be used in all cases. Compression fittings are not satisfactory at 200 lb. or over. All tubing should be machine-threaded rather than hand-threaded. All unions should have ground seats.

On machines employing a gear pump, a reservoir holding not less than $1^1/_2$ times the capacity of the pump per minute should be provided. The return flow of oil, both from the relief valve and from the cylinders, should always enter the reservoir at a point below the surface of the oil in the reservoir so as to have a closed circuit.

It has also been found that cast iron containing from 10 to 15 per cent of steel and high in chromium and nickel is very satisfactory for cylinders on 200-lb. work. A cast-iron piston head without rings but provided with very shallow V-shaped grooves at $^1/_4$-in. intervals is satisfactory. Cylinders and pistons when made of this material show practically no wear after a year of service.

It has also been found that the cup leathers or packing of any kind on the piston head are unsatisfactory when used in cast-iron cylinders.

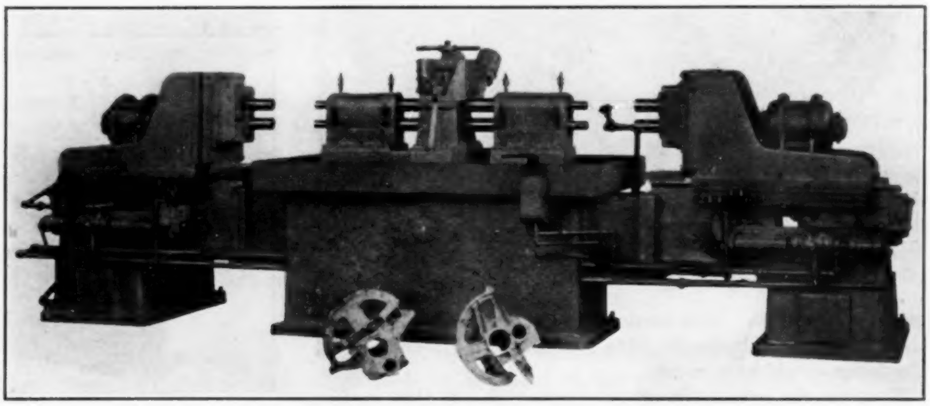


FIG. 8 ANOTHER TWO-WAY MACHINE CONSTRUCTED FROM 6-IN. UNITS

## Discussion

W. F. J. FORWARD.[1] Our first order for machines equipped with hydraulic feed was accepted with more reluctance than enthusiasm, and principally to satisfy a customer who insisted on hydraulic feed or nothing. However, these machines exceeded our expectations as to flexibility on production, and as a result changed our entire attitude toward hydraulic movements on machine tools.

Generally speaking our experience justifies the statement that all the advantages Mr. Ferris mentions in his paper are common to hydraulic feed, providing it is properly designed and installed. By properly designed I mean that the cylinder area chosen and the type of pump used to operate the cylinders must be given careful consideration if the machine is to perform as anticipated. By properly installed I mean that piping for 1000 lb. oil pressure is entirely a different matter from piping for city water pressure. Seamless steel tubing with compression fittings and long-radius bends wherever possible instead of elbows, give the best results.

[1] Engr., Consolidated Machine Tool Corp., Rochester, N. Y.

It is almost impossible to prevent some oil leakage especially during testing, getting air out of the system, etc. Therefore, we prefer setting the entire machine in a shallow floor pan.

Good workmanship is also important; particularly should the cylinder walls and piston rods be very smooth if a smooth travel is expected.

We have found hydraulic pumps to be very reliable pieces of mechanism. Our first troubles were blamed on the pumps, but were usually found elsewhere—such as wrong piping or some dirt carelessly left in the piping during assembly.

As to cost, sometimes the use of hydraulic movements tends to simplify a machine, and sometimes it does not. However a machine incorporating properly designed hydraulic movements is usually more flexible, safer, and more reliable, and therefore should be worth whatever it costs compared to a similar machine with mechanical movements.

It seems logical to expect that the use of hydraulic pressure for clamping, locking, feeding, main driving, etc., on machine tools will expand as fast as suitable equipment becomes available.

George T. Huxford.[2] Mr. Ferris made some mention of the application of the hydraulic-drive principle to heavy face-

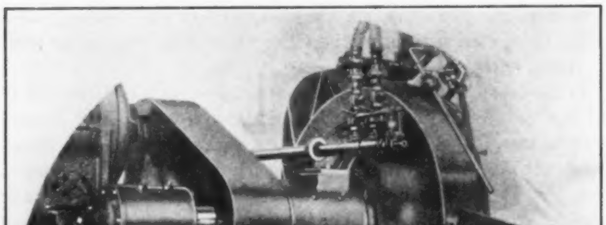


Fig. 1 Hydraulic Control on Grinding Machine

grinding machines. This particular type of machine illustrates the possibilities of hydraulic drive so well that a little additional discussion should be in order.

Consider the inherent needs of these machines, that is, fast table speeds with frequent reversals of heavy tables ranging from 7 ft. to 18 ft. in length. With the standard gear drive three speeds were provided, the maximum, except in special machines, being 35 ft. per min. This made the grinding of hardened steel, for example, slow, often injurious, and sometimes prohibitive, due to the relatively great concentration of local heating, and difficulty in maintaining sufficient coolant at the cutting points. Much greater speeds were not used because of limitations in the table-reversing mechanism. Even the speed variations available were seldom made use of by the operator due to a general reluctance to shifting belts.

[2] Engineer, Diamond Machine Company and Builders Iron Foundry, Providence, R. I.

Fortunately, in the case of our face-grinding machine, the hydraulic drive was easily adapted to standard design and allows further concentration of controlling mechanism at the operator's position. We were able to set the rotary oil motor referred to by Mr. Ferris and shown in Fig. 1 conveniently close to the initial drive shaft of our regular main gear train so that one pair of additional gears could transmit the power, and by this means any desired maximum speed can be built into the machine.

Speed variations are instantly obtainable by simply adjusting the oil control lever indicated by the arrow. This regulates the pilot valve of the pump shown in Fig. 2. The range of

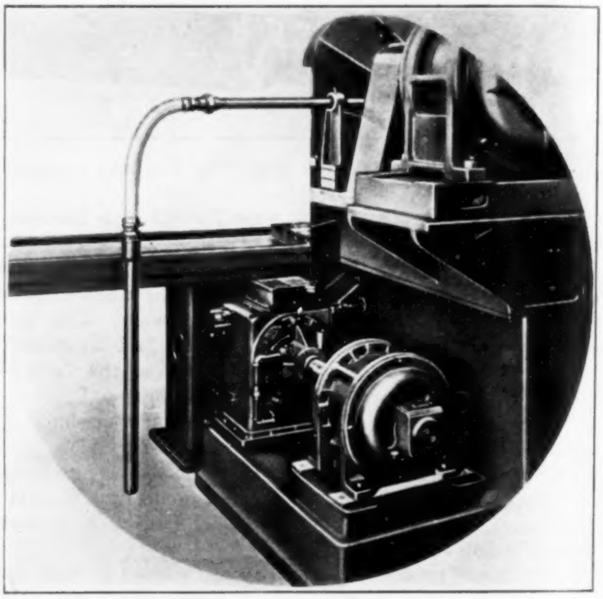


Fig. 2 Hydraulic Pump on Grinding Machine

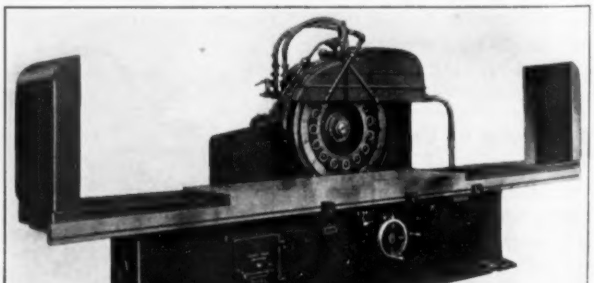


Fig. 3 Grinder with Hydraulic Feed

from 5 to 75 ft. per min. includes the usual required speeds and a substantial high- and low-speed reserve as well.

The advantage of the high table speeds is well illustrated by results at a large steel mill where they had trouble grinding high-speed steel on our belt-driven machines. With their present hydraulic-drive machine this trouble is definitely eliminated. Another firm doing similar work reports over twice the production with its hydraulic-feed machine.

The operator speeds up the table for roughing cuts and reduces speed for the final cuts if accuracy or special requirements of finish demand it. (See Fig. 3.)

The question of rapidly reversing a heavy table has always

been an important one to the face-grinding-machine designers. With the machine operating at a fast table speed working on a relatively small casting, 30 in., 18 in., or even less in length, the time required to reverse the table becomes an important factor in the total grinding time, in some cases exceeding 50 per cent.

It is obvious that in these cases production may be doubled by the oil drive which is sensitive and dependable and may be so set as to reverse without running the work entirely off of the wheel, thus making cutting continuous. So hydraulic drive, with its ability to handle the reversal of a rapidly moving, heavy table, has opened new fields for face grinding.

One vital function to be governed is the speed of the work table and for any given machine a definite quantity of oil delivered to the working cylinders produces a definite movement of the work table. It should be recognized that this question of volume per unit of time which determines "speed" is independent of pressure. That is, the pressure required to operate a machine is a constant for a given load, irrespective of the speed, and varies only as the load except for irregularities at the time of reversal.

If a central supply system is used, as has been suggested, letting a little oil into each cylinder a lot of power is wasted because the pressure must be built up to the maximum required by any machine, and probably used in some machines where much less is required. On the other hand, with a heavy pressure available, if it were freely connected to the cylinders opposed by a relatively small load, the speed of the table would be rapidly accelerated from its initial to an excessive point. In other words, each individual unit should be controlled in the same way as the speed of an electric motor driving an individual machine, by building up only the necessary driving force.

In regard to power required, the individual constant-delivery pump stands about half-way between the individual variable-delivery pump which uses the least power, and the accumulator which uses the most power. With the individual pump it is only necessary to build up a pressure in the cylinder equal to the resistance of the cut. It takes only half as much power to deliver, say, 500 lb. to the cylinder as it does to deliver 1000 lb. which might be needed for the maximum load. Therefore, if an accumulator is used for the 500-lb. job, half the necessary power has been wasted.

In our surface-grinding machines where the total driving power is small, we use gear pumps and also control valves which bypass part of the oil for slower speeds. We can regulate the oil bypass valve to suit the load and thus regulate the speed. In this case we do generate more power than we use on slow speeds but as the total power required is only 2 hp., the loss due to bypassing oil at slow speed is negligible. For our face-grinding machines where the total power is 7 1/2 hp., we use the variable-delivery pump, thus securing maximum efficiency.

A. M. Hammond.[3] Mr. Ferris mentioned the application of hydraulic drive to face-grinding machines briefly and Mr. Huxford has gone into more detail in regard to this. It occurs to me that as engineers you will be interested in the troubles which we had, at first, and how we have done away with them.

One of the most annoying troubles came with oil leaking through threads due to the high pressure. After considerable experimenting we found that this could be corrected by sweating solder on threads. It was found advisable, too, to use welded joints and pipe bends in some parts of the system.

Another difficulty was due to noise caused by vibration which was, of course, especially prominent at reversals. This was corrected by the addition of an oil dashpot.

The important thing is that the troubles have been overcome and without sacrificing any of the advantages. So, briefly, we believe that the face-grinding machine is indebted to hydraulic drive for slower speeds, faster speeds, smoother operation, and greater ease of control.

R. E. Flanders.[4] Both Mr. Ferris and Mr. Einstein have emphasized the advantage of elasticity in hydraulic feeds and that is rather surprising to the man who still sticks to screws and nuts and pinions, because he has always found that as elasticity is eliminated conditions improve. What is the difference between hydraulic and mechanical elasticity? Is it a difference in kind or in degree. If it is in kind, I would like to have it described. If it is in degree, is it a fact that there is more elasticity in hydraulic feeds than in mechanical? If that is all there is to it, it is the easiest thing in the world to put more elasticity in the mechanical feed.

The elasticity of the oil has been mentioned. How is the elasticity of the oil separated from the elasticity of the chambers, cylinders, and pipes within which it is confined? Is not, perhaps, the elasticity of the cylinders and communications fully as much concerned as that of the oil itself?

O. W. Boston.[5] In the papers which have been presented practically nothing has been said about tool life. The time element and the flexibility of the reciprocating motion and different feeds were emphasized, however. I have been particularly interested in hydraulic feeds from the point of view of their influence on the cutting action of the tool.

A number of people representing manufacturers of drilling, broaching, and milling machines equipped with hydraulic feeds, have made the statement that they have found greater tool life with hydraulic feeds than with mechanical feeds. I have a machine at the University of Michigan which will measure the force on a tool while it is cutting. I find whenever chatter occurs, particularly in cutting brass, that the force is much less, because of the chatter of the tool. I was unable to explain this phenomenon. I later heard from Professor Smith, of the University of Manchester, who is the author of the report of the Lathe Tool Research Committee of the Manchester Association of Engineers, and who reported that in his own experiments he was able to duplicate tests which showed clearly that the life of a tool while turning steel was greater under conditions which caused chatter. May there not be something in the nature of a natural period of vibration set up between the machine parts because of the compression of the oil or expansion of the oil containers, as the individual chip element is formed, which is so small as not to be noticed during the cutting action and which has very little effect on the finish? This to my mind, may have something to do with the increased tool life, if it exists.

M. Sklovsky.[6] We have been using hydraulic feeds on machine tools for a period of five years, beginning with special milling machines and later, drilling and boring machines and grinders. We have noticed particularly in nearly all cases that the chatter is reduced in the first place, secondly, that the feeds permissible are increased to a greater degree than was formerly possible, and thirdly, that the number of pieces per machine for a grinding of the tool is materially increased. All together, we have noticed about a 25 per cent increase in production on machine tools equipped with hydraulic feeds, and in some cases an increase of 50 per cent and more. That may not be due en-

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[4] Manager, Jones & Lamson Machine Co., Springfield, Vt. Mem. A.S.M.E.

[5] Prof. of Shop Practice and Director Engrg. Shops, Univ. of Mich., Ann Arbor, Mich. Mem. A.S.M.E.

[6] Chief Engineer, Deere & Co., Moline, Ill. Mem. A.S.M.E.

tirely in every case to hydraulic feeds, but the chief feature has been that of the hydraulic feed. On that account, we specify hydraulic feeds for machine tools, particularly for heavy-production machine tools.

There is just one objection we have to hydraulic feeds, and that is the cost. On that account we limit its application to machines costing several thousands of dollars or more each. Some day we probably shall simplify the hydraulic-feed element on every machine tool by installing a central system in the shop. We do not put in a generator with every machine tool, we do not put in a compressor with every machine tool, and there is no reason for installing a pumping system with every machine tool where a number are to be equipped with hydraulic feeds. It would very materially reduce the cost of building a tool if there were just a few simple pipes and valves furnished in addition to the feed cylinder, eliminating thereby the motor and pump.

Usually the hydraulic-feed mechanism is supplied with an independent motor which adds to the expense. These motors are furnished extra large, usually two and three times too large, and the power factor naturally drops so that with a number of machines in one group the result is poor. We would like to see a central system developed for this reason.

E. F. DuBrul.[7] I can see that a good many of our machine-tool designers are going to have to brush the dust off their old textbooks on hydraulics. They became electrical engineers with the electrical application, and now they have to become hydraulic engineers with these hydraulic applications. Incidentally, the executives of the machine-tool building concerns, I think, had better begin to forecast a little about how to furnish the funds to pay for that sort of talent.

The user is beginning to see something of what has been produced for him. One speaker has said that a machine gave him a 25 per cent increase in production, but he could not afford to use it because it cost too much. It might be that for 25 per cent increase in production it did cost too much, but what about those who get 50 and 100 per cent increase?

The fact, is, however, that all three elements of the machine-tool industry—the designing, the producing, and the using elements—are witnessing a very important development. It strikes me that perhaps this development has gone just far enough to justify the men who are concerned in it in getting together in intimate groups and discussing some of the more fundamental problems that may underly these differences and the relative fields and merits of various applications, such as the gear pump, or the accumulator, or the central plant. Possibly through such a conference of hydraulic machine-tool engineers they might save each other much grief. That may be a far-visioned idea, but I submit it for the consideration of executives of machine-tool companies.

W. B. Updegraff.[8] I am connected with a company which for 78 years has been building hydraulic machinery, and for 20 years I have been following the construction and selling of that type of equipment.

As I sat here and listened I thought that the spirit of optimism that has prevailed here throughout the entire morning might lead the members present into trouble if they did not use a little caution, a little matured judgment. The pendulum might swing too far the other way. While it is not my purpose to decry the use of hydraulic machinery, there are limits beyond which hydraulic machinery may not be used to advantage. I do not say that it should not be used in the machine-tool industry. This is undoubtedly a coming field and one which will prove very profitable, both to the builder and to the user of the tools. I do approve, however, of what Mr. DuBrul has said, that a pooling of interests would undoubtedly be very helpful. Some of the remarks made here today show that within the last two or three years the people furnishing hydraulic equipment have been working at problems some of which the company with which I am connected solved many years ago. There are new problems coming up right along and it is undoubtedly a field that is going to be increasingly important.

We are using a planer which has an electrical reverse mechanism which our works management thinks is practically perfect and which we prefer to hydraulic mechanism. I, personally, will not have hydraulic brakes on the car I drive. I simply mention these things to show that there is a definite field for hydraulics and others for which hydraulics is not thoroughly adapted.

R. M. Galloway.[9] There is no controversy between the two methods of oil feeding. We use both systems and for rather definite reasons as far as we are personally concerned. When the pressure required in the drilling is somewhere around 6000 or 7000 lb. total, we do not use a constant-flow, constant-volume pump. We use the oilgear or some similar system. When large, we use the variable pump. When the drilling load is light and where we have several heads which we want to operate with as compact and cheap a unit as possible, we use the other system.

William F. Parish.[10] Just a word about oil. In the 25 years that I have been attending meetings of the Society, we have had quite a number of notable developments, including many types of steam engines, steam turbines, gas engines, Diesel engines, automotive engines, and aeronautic engines. In the general discussion between the machine manufacturers and the operators of this machinery it has become evident that many of the difficulties that they have had during the early stages of development were largely on account of the oils used in the various systems for either lubrication or fuel. Operations have been conducted on these various developments in many plants and the machinery has been well designed, properly built; under test or in actual operation during the early stages the greatest variable and one that has made the records so widely different has been due largely to the lubricating oil and the method in which it was used and to the fact that the application as well as the nature of the oil had not been standardized for that particular class of machinery.

In connection with the development of our intricate machinery the standardization of the lubricants and fuels has not come until such machinery has been commercially acceptable and has been in operation for many years and when the supply of lubricants and fuels had become a question of considerable importance to the oil industry. The standardization of the petroleum takes place at a time when it is not particularly helpful to the engineers and machinery builders during the expensive and rather discouraging period of development.

In the development of the hydraulic systems attached to machine tools, there is no doubt whatever that all of the various manufacturers developing this machinery are using different kinds of oils as the medium of power transfer and that the systems, as far as capacity and other features that effect petroleum are concerned, vary to a considerable degree. Many of the difficulties mentioned by the speakers at this meeting are un-

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[9] Chief Engineer, National Automatic Tool Co., Richmond, Indiana.

[10] Construction Lubrication Engineer, 17 E. 42nd St., New York, N. Y.

doubtedly due to the changes which take place in the oil through conditions under which it is forced to operate and to possible contaminants of one kind or another which invariably enter circulating systems operating with oil. Oil that circulates rapidly in a closed system will undergo gradual change in character dependent upon the rapidity with which it is circulated, upon the heating and cooling, upon pressures, and upon contamination. If there is a small amount of oil in the system and it is circulated at high speed under high pressure, meeting with temperature at the point of contact of the gears or at some other point in the system, volatile matters will be liberated and these form gases that will have the same effect in a pressure system as air. With the liberation of volatile matter, as a rule, gums are formed which collect solid matter and result in deposits in the clearances. Moisture or water always gets into a circulating system. This can be caused by condensation of the air or by outside leakage and the effect of water working with oil in such a system is to cause emulsions, which gradually solidify into deposits.

In the continual circulation of petroleum it undergoes a gradual change that is indicated by an increase of acidity; when oils build up in acidity there is a point where they will form emulsions much more rapidly with water and undoubtedly will undergo many other changes due to forces that are acting upon them, such as the continual agitation and possibly oxidation. Then there is the final question of contamination. When such a system is working on a machine tool there is, of course, the lubricating oil, the cleaning oil, and the cutting oil used around the same machine and the possibility of contamination from these sources.

I have this to suggest to the research men: that they arrange their force-feed systems for a maximum quantity of lubricants so that a large amount of the oil can be brought to a complete rest in the tank provided with settling compartments so that the heavier matter can be settled out; that they arrange for temperature control either by heating or cooling for such installations where exposure to wide range of temperatures will be encountered; that every care be taken so that the lubricants, cutting oils, or soap mixtures will not enter the system. The character of oil to be used in the system should be what is known as a neutral oil filtered by the refiner and having a viscosity of not over 125 sec. at 100 deg. fahr. on the Saybolt Universal. This oil should be a highly finished lubricant, preference being given to that lubricant which contains the least volatile matter.

W. J. Peets.[11] It has cost us a great deal in the past to design special drilling machinery. When the design of a piece changes so that even one or two holes are changed, the entire machine is likely to be scrapped or become obsolete. The ability to get units which can be fed independently and shifted around on a machine at will, will, I think, give us cheaper machinery, machinery that can be changed over very easily and quickly, and will make it possible to tool up production in much smaller lots than at present.

D. H. Montgomery.[12] In our work we ran into a problem that seemed interesting—the elimination of the high cost of air in operating ordinary air-operated chucks, the use of which is proposed on a machine under development. It took from one to one and a half horsepower to maintain the operation of a chuck and, in addition, the pressure was variable. The whole shop depended not only on a stated pressure but there must always be a reserve on hand. The accumulator was then tried.

The usual accumulator is leaky and bulky. The air accumulator has the disadvantage of high variation in pressure. In holding work in the chuck we had to be sure that the instant the chuck was closed, a predetermined pressure was available. We then got the idea of using a small pump driven by a motor. The pumps would actuate the chuck itself in probably less than 30 or 40 sec., but by means of a bypass valve unaffected by back pressure we could discharge air into the accumulator and built up gradually a pressure equal to the pressure originally set on the pump, the back pressure on the pump being always available at the chuck.

The small power consumption, of course (a quarter and a half horsepower) proved to be a big advantage. It gives air flexibility and an extremely simple mechanism, and to get away from the difficulties with oil leaks, we have put the entire mechanism within the tank so that the whole unit takes up a small space.

J. J. Crain.[13] We have been manufacturing hydraulic variable-speed transmission for about 20 years and most of our products have gone to the Navy. Someone asked about the time required for reversals. We have had some interesting experience along that line. The Navy Department specifications require that we reverse the turrets from full speed in one direction to full speed in the other direction in two seconds. We are always able to meet this specification. We do it in from $1^3/_4$ to $1^5/_8$ sec. A modern turret weighs nearly 1500 tons, and full speed is 100 deg. per min. The older turrets weighed somewhat less and had a speed of 1 r.p.m., or 360 deg. per min. These reversal requirements are way beyond anything required of even the largest machine tools. But the characteristics of variable speeds are well adapted to quick reversals, and for the small weights in machine tools, the reversals can be made in a fraction of a second without difficulty.

Walter Ferris. Mr. Montgomery spoke of the adaptation of a small pump to an air chuck. We have long had the machine chuck in view as a device that we think can be operated hydraulically to greater advantage and with more economy than by air. If this chuck were operated by an oilgear pump, the diameter of the piston used would be about one-third what is now necessary to get an amply strong application. If a small pump is used, quick advance will be gotten by an oil and spring accumulator, or by an oil piston with compressed air over it which will be ready to unload instantly just as does the air piston. Only one-tenth of the power will be used and the oil will hold a chuck better than air will.

Mr. Updegraff spoke of the electric planer and said that his company considered it perfect. The electric reversing planer is now a very beautiful machine, but five or six years ago when we tried to introduce hydraulic feeds in place of mechanical, users asked what was the matter with the mechanical feed. There seemed to be no reason for hydraulic feeds. As I watch the electric planer, it requires probably a foot of travel to get up to full return speed and many times it is never reached. If I were suggesting the possibility of hydraulic planers I would say that the strongest reason for the hydraulic planer is that a much quicker reversal is feasible. We would probably not reverse the pump at all because it takes the pump about a second and a half to bring about the complete reversal. A 4-way piston valve will reverse the flow instantly. As I visualize the large planer hydraulically operated, I see the table going backward and forward on a 4-in. stroke, and I see that table accelerating from its reversal point to a reasonable cutting speed within 2 in. If the hydraulic planer can do this, and perhaps it can, I submit that the electric planer is not the best that can be imagined.

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[12] Engineering Agent, National Acme Co., Berlin, Conn. Assoc-Mem. A.S.M.E.

[13] General Manager, Waterbury Tool Co., Waterbury, Conn. Mem. A.S.M.E.

The next subject I would like to discuss is the nature of the cutting action. We can only guess at the nature of cutting action as affected by a multiple-plunger pump operating in a closed circuit. We built a broaching machine, and as the broaching machine was originally driven by a screw we compared the characteristics of the hydraulic with the screw method of operation. We can now state, as I think it has been proved, that it takes 5 to 8 per cent less force to pull the same broach through the same piece of work at the same speed when it is pulled hydraulically than when it is pulled by a screw. This saving is not important commercially, but if a hydraulic piston will do the work with less force than a screw, there is something to think about.

Sol Einstein. As we build various machine tools, our problems in the application of hydraulics will be somewhat different. A circuit, as it is applied to a certain tool, cannot be transferred to a different tool. The problems are different and therefore it is best to apply general principles to the particular problem.

When we made our experiments on hydraulic feed on milling machines, we found that on the same machine, using either hydraulic or mechanical feed, there was a tremendous increase in the rate of feed possible with the hydraulic feed. This feed naturally varies with the nature of the cut, but there has been from 50 to 350 and 400 per cent increase of feed rate on the same type of machine. We feel that sooner or later the large majority of machine tools, with exceptions, naturally, will have to make use of the hydraulic arrangement for feeding purposes in order to maintain the standard which the American machine-tool industry has not only in this country, but throughout the world.

H. Ernst. In regard to the compressibility of the hydraulic medium: We all know that oil is really compressible to a considerable degree, the relation between compressibility and pressure being generally expressed by the term "bulk modulus." Up to the present time, however, very little information has been published relative to the effect upon compressibility of such variables as viscosity, temperature, and pressure.

We know, too, that compressibility of the hydraulic medium is very closely associated with the increase in tool life which we get with hydraulic feed as compared with mechanical feed. We are not yet prepared to give definite figures in regard to increase in tool life; we know it exists, but the actual increase is affected by a great many factors which, at present, are a little beyond exact determination.

A table moved by hydraulic pressure acts differently from one moved by mechanical means. In both cases there is a yield under increase of load, and a forward acceleration upon release or reduction of load; but the extent of yield under impact and the rate of advance on release of load are radically different in the case of hydraulic feed. Here we have a true "cushioning" effect. As each cutter tooth strikes the work the table definitely yields a minute amount, thus absorbing the shock and reducing the impact, energy being dissipated by a momentary increase in leakage and by internal friction in the oil column. Furthermore, by the use of the locked hydraulic system, the small forward jump (which occurs on release of load) is greatly retarded due to the counter pressure automatically built up on the opposite side of the piston. The table thus, in effect, executes a highly damped free oscillation, automatically adapting itself to the load variation.

The differential control valve, as described in the paper, acts to maintain a desirable relationship between the pressure acting on opposite sides of the piston, in accordance with the cutting force. That is, in accordance with the horizontal component of the force produced by the action of the cutter on the work. This valve also acts to retard the forward jump of the table under release of load, by virtue of its stabilizing action on the entire hydraulic circuit.

One of the principal reasons for adopting the locked hydraulic system in preference to a more conventional type of circuit was to insure a positive control of table movement, independent of the direction of action of the resultant cutting force. Under certain conditions of milling, particularly in face milling, the normal direction of the cutting force may be completely reversed at the end of the cut and the cutter may then tend to drag the table in the direction of the feed. Furthermore, in certain instances downward movement of the cutter upon the work is highly advantageous. Thin slotting saws work much better when operating in this way, and in some cases this method may also be profitably used in ordinary spiral milling. With the locked system, irrespective of the direction of the cut, the table can advance only as fast as the oil is metered out from the discharge end of the cylinder.

In answer to Mr. Flanders' question regarding the use of a booster pump in connection with our system: In order to maintain an active forward pressure under all conditions of operation and to compensate for the difference in displacement on opposite ends of the cylinder due to the piston rod, it is necessary that there be always available a small excess of oil. This is supplied by the booster pump and in hydraulic parlance, is generally referred to as "make-up oil."

It is true that the excess oil supplied by the booster pump and not required in the circuit may be returned to the reservoir by way of a simple relief valve instead of by the more complex differential valve which we use, and in our early work the simple valve was actually successfully used. The differential valve, however, possesses the following advantages:

Analysis of our circuit shows that the amount of forward pressure sets a definite limit to the amount of cut that can be taken. For instance if we use a simple relief valve set to maintain a constant forward pressure of, say, 600 lb. per sq. in., and acting on a piston area of, say, 10 sq. in., there will be a total forward pressure of 6000 lb. When the table is idling, the back pressure will be approximately equal to this. Now, if a cut be taken in a direction opposite to the feed and if its amount be such that the horizontal component of the cutting force be equal to 6000 lb., then the forward pressure will be completely balanced by the cut, and thus the back pressure will be reduced to zero. This, then, is the limit of the cut which can be taken. It is impossible to feed faster than a rate which produces a cutting resistance equal to the amount of the forward pressure.

With the differential valve, on the other hand, and reduction of back pressure due to the action of the cutting force causes a corresponding increase in the amount of the forward pressure. Thus, for a given idling pressure the capacity of the machine will be greatly increased and, conversely, for any desired maximum pressure the necessary idling pressure will be correspondingly reduced. By varying the ratio of the areas of the two valve portions, any desired pressure regulation may be obtained. We have adopted a compromise ratio of about 3 to 1, which is satisfactory for the various conditions encountered.

A further advantage of the differential valve is its effect upon the stability of the table movement. On account of its action in maintaining a proper pressure balance in accordance with the instantaneous requirements of the circuit, it acts to dampen the table oscillation under fluctuation of the cutting force. Thus it tends to increase the true "cushioning" effect of hydraulic feed.

This apparently irregular movement of the table—the characteristic natural adaptation of a hydraulic feed to changes in the cutting force—must not be confused with chatter. It is not chatter, and does not affect the finish produced on the work.

# The Economics of Machine-Tool Replacement

## Present Market Conditions and Tendencies in Machine-Tool Design; Comparison of New with Former Types of Machine Tools and Savings Effected by Replacements

By MYRON S. CURTIS,[1] PAWTUCKET, R. I.

THE ECONOMICS of machine-tool replacement is a subject that is of vital importance both to the machine-tool builder and to the machine-tool user. This is the sole excuse for this paper, for the information given will be found to be neither decidedly new nor of a radical nature.

There is no question but that the period of enormous expansion in practically every manufacturing line, and particularly in the automotive industry, which has been witnessed in the last fifteen years has ceased, at least for the present. While it is entirely possible that there may be extensive development and expansion of certain lines, which will in turn affect certain branches of the machine-tool industry, still it is extremely doubtful that we shall see any general expansion. For example, the automotive industry is beginning to realize that it must depend for its dividends upon increasing the profit per unit rather than upon increasing production. As opposed to this we find the machine-tool industry in an over-expanded condition due to the enormous demands made upon it by the growth of the automotive industry and by the conditions brought about by the World War. Also, machine tools of today are of a much more rugged nature, and are more foolproof in construction than those of a few years back, thereby extending the probable life of the machine tremendously. Again, improvements in the design of machine tools have generally increased the productive capacity from fifty to in some cases six hundred per cent, again reducing the potential market. It is easy to figure that if a tool put out by a machine-tool maker today will do twice as much work as one put out by him five years ago, all other things being equal, he will only sell one half as many machines as formerly.

Outlet must be found for at least a reasonable percentage of the capacity output of the machine-tool industry. If it cannot be absorbed by expansion it necessarily follows that it must be absorbed by replacement. This, in turn, may be caused either by the development of improved methods of manufacture, that is to say, the replacement of a machine tool by one of an entirely different nature, or else by improvements in the machine tools themselves, whereby a lathe is replaced by a lathe, a milling machine by a milling machine, and so forth. The machine-tool builder has had and always will have an increased field by developing improved methods of manufacture, not only in hundreds of shops where obsolete methods of manufacture still exist, but even in the up-to-date production shops of today.

This question of machine-tool replacement is also vital to the machine-tool user. There is no doubt but that, with the keen competition now existing in all manufacturing lines, the organizations which survive will be those which have equipped themselves with the best plant and personnel. This particularly applies to industries in New England.

The tendency to cling to obsolete machinery simply because it is in good condition and is capable of doing about the same amount of work which it did when it was installed, will eventually put any concern out of business. There should be no more hesitation in scrapping an old or inefficient machine than there is in getting rid of inefficient men. As a matter of fact, the obsolete machine is a greater liability to the plant than the inefficient man. J. A. Smith, the general superintendent of the General Electric Company, which is one of the biggest users of machine tools in the country and a concern which has to meet the strongest kind of competition, says,

> I believe it is thoroughly bad for shop morale to keep a lot of superannuated machine tools standing around. They occupy valuable space that ought to be devoted to a productive machine. They tie up motors that ought to be working. If your equipment is obsolete, sell it. If you can't sell it, scrap it. It is too expensive to have around the shop.
>
> No concern equipped with obsolete tools can hope to compete these days, and the only cure for the ailment is amputation and replacement.

What makes a machine tool obsolete? Two things: first, the nature of the tool and the way it has been treated; second, the developments of the art through which the modern tool produces more than the one it supplants. In regard to the first reason, a tool may be in such shape that it is unable to produce sufficiently accurate work, or it may be that repairs are altogether too frequent, and result in excessive waste of productive time. This may be due to faulty design of the machine tool or to careless handling, particularly in regard to keeping the machine clean and oiled. A machine tool may be obsolete for the work it is performing, but may be very useful and economical on some other job. In such cases the tool should be transferred to the other work and a new tool provided for the work which is beyond the capacity of the first one. If, however, there is no job on which the tool can be economically placed, it should be immediately scrapped, as it is too costly to use.

The second reason for machine-tool obsolescence is due to the improvement in the art. The machine-tool industry has made enormous strides in the last five years. During the war and for some years previous a machine-tool builder, no matter what his product, was able to sell the capacity production of his shop, and therefore the average manufacturer was not particularly interested in making any radical changes in his product. He was concerned solely with production. Immediately after the Armistice, however, conditions changed, and the market for machine tools became a buyer's market instead of a seller's market. This caused the up-to-date manufacturer to start redesigning and improving his line, so that today it is safe to say that nearly every type of machine tool built prior to 1921 is totally obsolete for production. The machine-tool builder is designing to take feeds and speeds which were unheard of even five years ago, and is taking full advantage of the developments in high-speed cutting tools. Five years ago the art of making cutting tools was far ahead of machine-tool design. Few if any machines were capable of forcing high-speed steel to the limit. Today this condition has changed, and the capacity of the modern machine tool is dependent wholly upon the ability of the cutting tool to stand up. Of course, all machines built five years ago are not obsolete for all classes of work. Certain jobs are inherently too weak in themselves to withstand heavy feeds and speeds, or can be machined just so fast because of the distortion due to heat and the limits required.

[1] Potter & Johnston Machine Co.

Presented at the First National Meeting of the A.S.M.E. Machine Shop Practice Division and the New Haven Machine Tool Exhibition, Mason Laboratory, Yale University, New Haven, Conn., September 6–9, 1927.

### Tendencies in Modern Design

It will be well at this time to point out some of the improvements in design by which these results have been brought about. There are three main tendencies.

1 Increased power and rigidity together with the correlative ability to withstand abuse
2 Increased convenience for the operator
3 More foolproof construction.

Some of the tendencies toward increased power and rigidity follow:

More and better placed material is used in beds, gear boxes, carriages, etc. Thirty years ago most machine tools, especially those of British manufacture, were extremely heavy. Gradually the lines were refined and excess material was done away with. Then came the introduction of high-speed steel, and nearly every machine tool on the market proved to be too light to withstand the heavy duty imposed. The metal which was removed has been gradually put back, especially since the importance of freedom of vibration to cutting-tool life has been learned. Today, machines are made not only strong enough to withstand the strains imposed, but also heavy enough to absorb all vibration at the cutting edge of the tool.

There is a definite tendency toward the use of alloy steels for shafts, gears, etc. This is a direct result of knowledge gained from the automotive industry, and today, every good machine tool has its high-duty gears and shafts made of heat-treated alloy steel. Another direct result of the influence of the automotive industry is the use of anti-friction bearings for all fast-running high-duty shafts. A more recent development has been the use of anti-friction bearings for spindles of lathes and milling machines. Certain light high-speed machines, such as woodworking machinery, drill presses, grinders, etc., have long employed anti-friction bearings for spindle mountings but it is only lately that successful applications of anti-friction bearings to high-duty spindles such as those of lathes and milling machines have been accomplished. This is a long step forward, resulting as it does in increased accuracy, lessened friction, and longer life of bearings.

Increased convenience of operation has been accomplished by well-thought-out design in the grouping of levers, the accessibility of change gears and cams, etc., all of which cut down the setting-up time materially, and by reducing fatigue, make it possible for the operator to produce more work in a given time.

More foolproof construction is absolutely necessary today, as the class of help operating machine tools under production conditions has definitely changed to unskilled labor. A production tool is no longer operated by a mechanic—a man who understands its various functions, and who takes pride in keeping his machine running smoothly and efficiently. This type of man can no longer be found in sufficient numbers to operate our shops. The use of interlocking levers, safety devices such as slip frictions and shear pins, and, on some of the simpler tools, hydraulic feeding mechanisms is therefore noted. The matter of oiling has also received considerable attention. Five years ago most machine tools were oiled by the old-fashioned oil can and the tool with any well-thought-out system of oiling was an exception. Today are to be noted the use of enclosed gear boxes running in oil, mechanical oiling systems such as have been for a long time used on engines, unit oiling systems usually with a sight-feed drip whereby one or two oil reservoirs oil the whole machine, and more recently, the development of the one-shot oiling system.

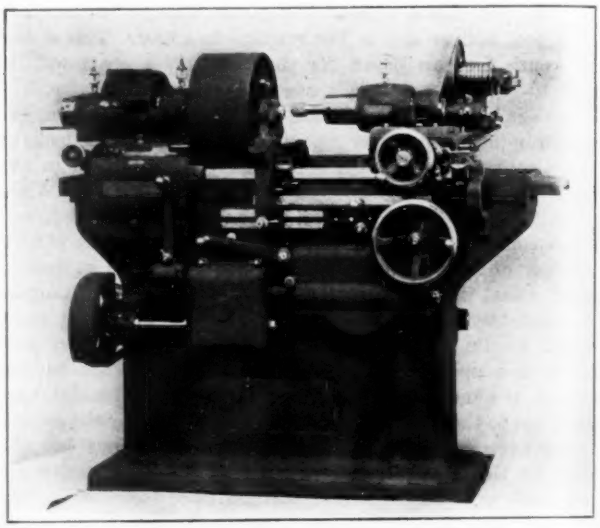

Fig. 2 Internal Grinder

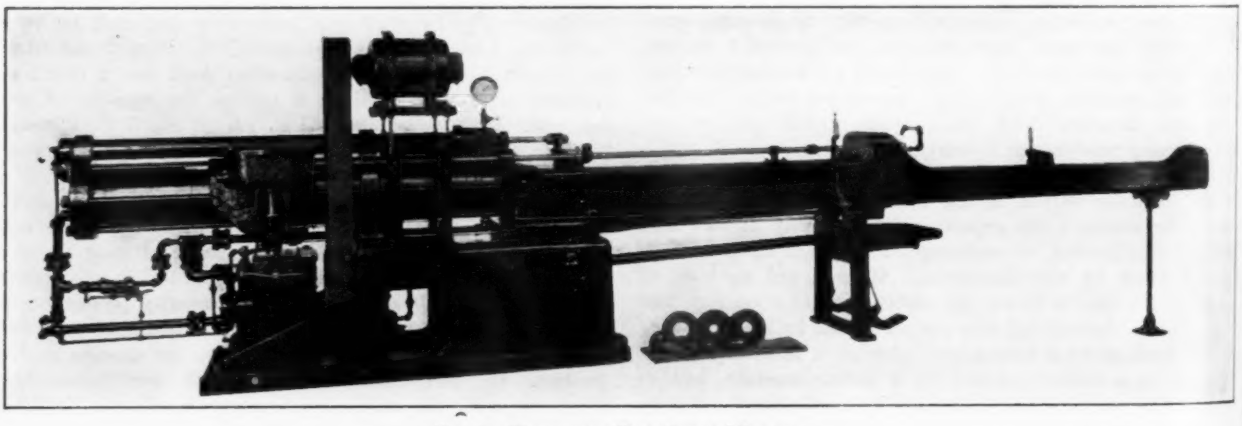

Fig. 1 Hydraulic Broaching Machine

These three general developments, namely, increased power and rigidity, increased convenience for the operator, and foolproof construction, have resulted in an enormous increase in the productive capacity of machine tools, and increase in production hours because of freedom from breakdowns.

### Comparisons of Present and Former Machine Tools

In the standard type of screw-feed broaching machine the

broach is pulled through the work by a rotating nut and non-rotating screw.

Fig. 1 shows the latest developments in hydraulic broaching machines. The crosshead and the draw head for adjusting the broaching tools are similar to those previously used in the screw-type machine. However, the crosshead is pulled by a piston rod instead of a screw, the piston rod being attached to a piston in an 8-in. diameter hydraulic cylinder. This hydraulic cylinder is connected with a variable-stroke pump, the displacement of which is controlled during the pulling

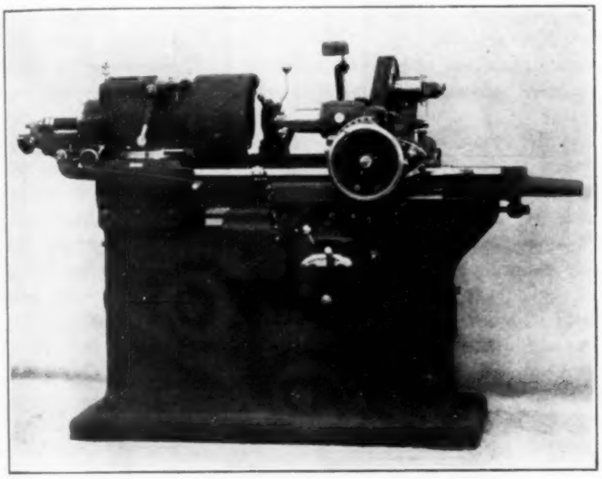

FIG. 3 PRESENT DESIGN OF INTERNAL GRINDER

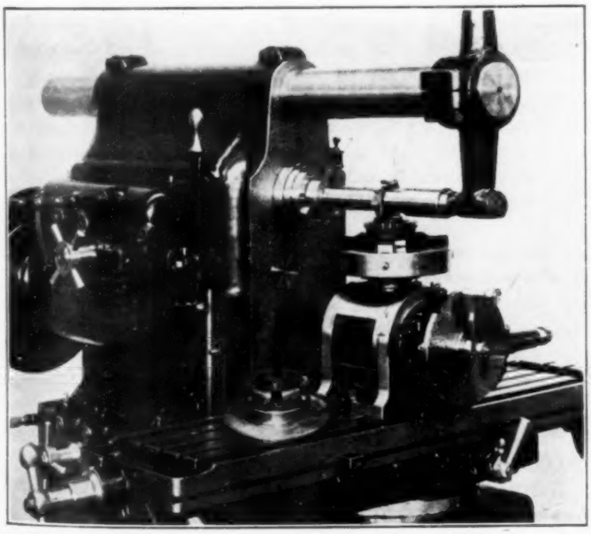

FIG. 4 MILLING MACHINE

and return strokes of the broach by tappets operated at the two ends of the stroke. These tappets operate the pump valve so as to give a slow feed and a quick return, and the feed can also be adjusted from zero to maximum by varying the stroke of the pump, thus allowing the best broaching speed to be obtained. In the pipe line is a release valve which may be set at any predetermined load. If for any reason the pressure rises above this amount, the valve operates to bypass the pump, relieving the pulling force on the broach to zero. With this safety attachment a serious breakdown is impossible, and the feed may be set near the capacity of the broach without fear of overload if the broach becomes dull, or if extra hard subjects are met with.

The great increase in production obtained by the hydraulic method is due to elimination of the great power loss from the friction of the screw and nut, which makes it impossible to run a heavily loaded screw broach at more than 4 or 5 ft. per min. cutting speed. Experience with the hydraulic method has proved that the hardest commercial material can readily be broached at a cutting speed of not lower than 12 ft. per min. while low-carbon steels are frequently broached at 25 to 30 ft. per min., an increase of from 250 to 600 per cent. The adaptation of the hydraulic pulling mechanism has also permitted broaches to be designed to take a good-sized chip, thus allowing a job to be done with one broach which formerly required two or three. The efficiency of the hydraulic broach is also about $4^1/_2$ times the efficiency of the screw broach.

A standard engine lathe of approximately five years ago was equipped with cone-driven backgeared headstock, countershaft shipping, and hand change-feed gears at the head end.

A recent model of this lathe has a single-pulley drive, ball-bearing headstock running in oil, and the speed change levers conveniently mounted on the headstock. The feed gearing is changed by a tumbler gear and cone, these gears being made of steel. The operating lever for starting, stopping, braking, and reversing the spindle is placed so that it travels with the carriage,

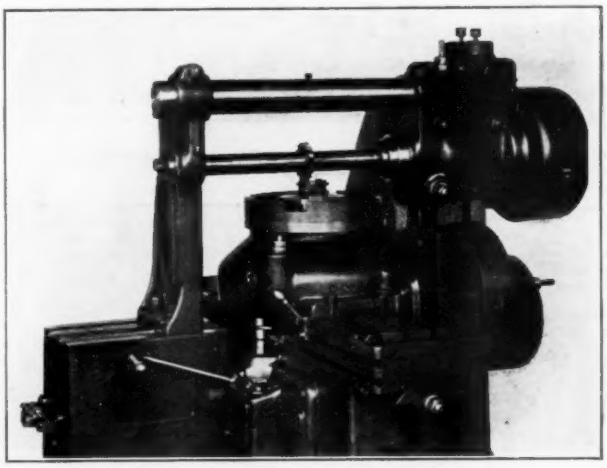

FIG. 5 PRESENT DESIGN OF MILLING MACHINE

thus always being within reach of the operator. The longitudinal feed is provided with multiple stops which can be set so as to automatically trip the feed at any desired position, thus enabling distances between shoulders to be duplicated without the use of measuring instruments. Multiple-diameter stops mounted on the cross feed screw allow diameters to be readily determined without the use of callipers. This machine is also equipped with a pan, pump, and tubing for applying cutting compound to the tool, thus materially lengthening the life of the tool and permitting increased cutting speeds. Although every one knows that higher cutting speeds and longer tool life are gained by the use of coolant, it is safe to say that at least 75 per cent of the lathes operated in New England shops are cutting without the use of compound. These various improvements in design have so increased the productive capacity of this lathe that the makers claim that a time saving of from 25 to 75 per cent may be made as compared to the ordinary engine lathes.

In a former type of flat-turret lathe, the head was of the cone

type with friction backgears. There was but one carriage, having power longitudinal and cross feeds which could be changed at the feed box on the head end of the machine, the feed reverse also being contained in this box. All changes were made through the shifting of drive keys, and to engage the longitudinal or cross feed in the apron, it was necessary to engage a worm with a wormwheel. The machine had no rapid traverse to the carriage and no centralized control.

In the present model of the same machine, the geared head has single-pulley drive, hardened alloy-steel gears running in oil, and automatic disengagement of the multiple-disk driving clutch when the gears are shifted, offering not only a practically instantaneous change, but also a foolproof construction. A cross turret has been added, and all feed changes are incorporated in the aprons, allowing instantaneous shifting of feeds without walking to the end of the machine to shift tumbler gears. These feed

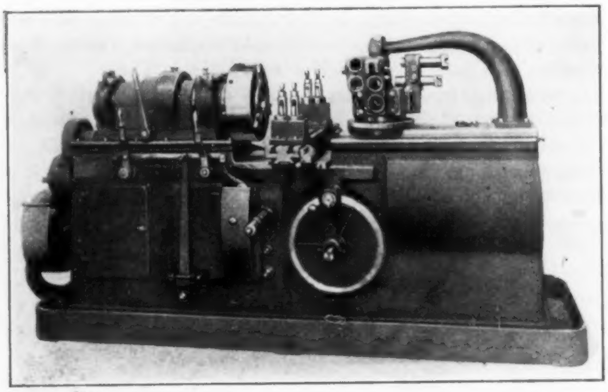

Fig. 6 Automatic Chucking Machine, Model 6*A*

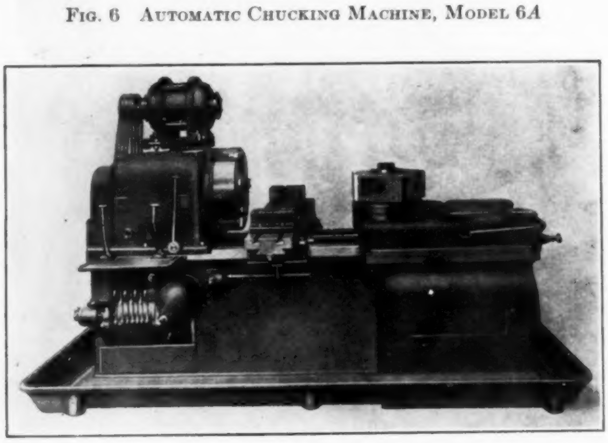

Fig. 7 Automatic Chucking Machine, Model 5*D*

gears are hardened, run in a bath of oil, and are mounted on square shafts running in ball bearings. A rapid power traverse in either direction is accomplished by a lever located on the apron. The operation of this lever automatically disengages the feed and the turnstile, another instance of convenience and foolproof construction. The added features in this machine have resulted in increased production of from 50 to 100 per cent, some users paying for the machine in six months by increased production.

Fig. 2 is an internal grinder of a few years back. It would seem from a glance that this machine was about the latest word in convenience, having as it does all levers centrally located, a quick-change gear box giving three rates of table travel for each work speed, automatic wheel guard, etc.

Fig. 3 shows the present design of this machine. The table is hydraulically driven, giving unlimited speeds, quick traverse for bringing the wheel to and from the work, and complete control of speeds and direction of movement at all times. An automatic short-stroke dog and a convenient wheel-truing device allow the operator to true his wheel just before finishing the work and are of great assistance in obtaining production and finish. The water starts and stops simultaneously with the work. Hand and automatic feed pawls for the wheel are provided.

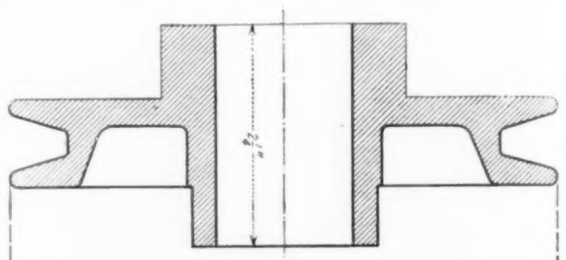


Fig. 8 Cast-Iron Fan Pulley

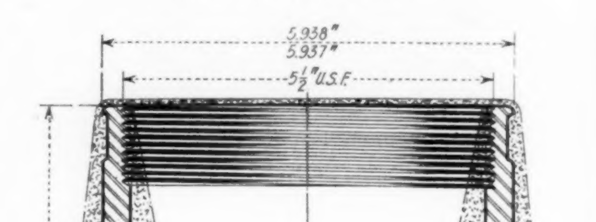


Fig. 9 Forged Differential Housing

These improvements and others result in the following increased production times:

Hardened steel bushings, $\frac{3}{4}$-in. hole, $1\frac{3}{4}$ in. long, limit 0.0005 in., increase from 45 to 100 per hr.

Hardened gear, $1\frac{7}{16}$-in. hole, $1\frac{9}{16}$ in. long, 0.0005-in. limit, increase from 22 to 70 per hr.

Bronze bushing, $1\frac{5}{8}$-in. hole, 2 in. long, 0.001-in. limit, increase from 18 to 60 per hr.

Ball race, $1\frac{3}{16}$-in. hole, $\frac{7}{16}$ in. long, 0.0005-in. limit, increase from 50 to 140 per hr.

Note that the increase in production ranges from 100 to 350 per cent.

An interesting comparison showing gain in production by the use of a modern-type milling machine is shown in Figs. 4 and 5.

Fig. 4 illustrates the old method of milling clutch teeth. The machine is of the old knee-and-column type with old-style round over arm, and tumbler construction for the drive. The time per piece was 7.65 min.

Fig. 5 illustrates the present method of machining the same piece. The machine used is a fixed-bed-type automatic milling machine. All operations including the indexing of the fixtures are automatic, and all that the operator has to do is to remove and load the work and start the machine. The time per piece is 3.58 min., less than half the time on the old-type machine, and due to the automatic features, one man can run several machines.

Fig. 6 is a model *6A* automatic chucking machine. The spindle gearing is located in the bed of the machine, all shafts run in plain bearings, and none of the gears runs in oil. The cross slide is fed by rack and pinion from the cam drum, and the turret drum is of cast iron with inserted hardened-steel strips. This model was standard five years ago, and is still satisfactory for certain classes of light work, but has, however, been superseded for heavy production.

Fig. 7 is the new model *5D* chucking machine. Some of the improvements in this model are as follows: an all-geared headstock, all gearing and shafting being of chrome-nickel steel hardened; all shafts running in anti-friction bearings, and the spindle itself running in anti-friction bearings. All high-speed gears are helical making a practically noiseless gear box. The bed of the machine has been strengthened throughout and is provided with hardened-steel ways ground in place in absolute alignment to the spindle. The turret slide is provided with hardened-steel bearing surfaces, and has been increased in size and strength. The turret seating has been greatly increased in diameter and is provided with a clamping device which does away with the old-style overhead arm. The turret cam drum has been changed from a cast-iron drum with steel strips bolted on, to a solid steel forging with the cam path milled from the solid and the whole drum case hardened. The cross slide is driven directly from its cam drum, and both the turret and cross-slide cam rolls are ball-bearing mounted. The feed mechanism has been simplified and at the same time improved so that any particular feed may be automatically obtained. The automatic changes of feeds and speeds are instantaneously operated by power, making it possible not only to drop from a high to a lower cutting speed, but also to jump from a low to a higher speed. The advantage of this improvement in doing long facing cuts is obvious. Besides being provided with safety couplings, the machine is oiled by a unit system.

Some of the results of these improvements have been startling, to say the least. Whereas a 10-hp. motor drove the first machine to capacity, it has been possible to put 48 hp. into the later machine without doing anything but stall the motor, and a number of machines are regularly using 25 hp. This is in spite of the fact that the anti-friction-bearing headstock shows an increased efficiency over the old-type plain-bearing head of from 30 to 50 per cent. Increase in production on this machine over the earlier machine has been anywhere from 50 to 300 per cent.

### Savings by Replacements

It is very apparent from the foregoing comparisons that the machine tool of today is incomparably more efficient than that of five years ago. There are however other elements which enter into the economics of replacing a machine tool besides the simple one of increased production.

The figure desired for comparison is the operating cost per hour which consists of the prorated annual charges plus labor plus power. These annual charges take into consideration depreciation; the average interest on the cost of the machine minus the interest earned by depreciation reserve; rent; repairs; and maintenance, such as oil, cutting compound, tools, etc.

The cost of the machine installed is equal to the cost of the

TABLE 1

**Machine: *6A* automatic**
**Subject: Cast-iron fan pulley**
**Production: 10 pieces per hour**
**Cost of machine and tools, \$3700**

| | |
|---|---|
| Annual charges | |
| Depreciation (10-year life) | \$370.00 |
| Average interest | 122.10 |
| Rent (same as *5D*) | |
| Repairs | 60.00 |
| Maintenance | 250.00 |
| Total | \$802.10 |
| Operating cost per hour (250 hours per month) | |
| Prorated annual charges | \$ 0.27 |
| Labor (1 man operating 3 machines) | 0.25 |
| Power | 0.07 |
| | \$ 0.59 |

$$\text{Cost per piece } \frac{0.59}{10} = \$0.059$$

TABLE 2

Machine: *5D* automatic
Subject: Cast-iron fan pulley
Production: 24 pieces per hour
Cost of machine and tools, \$5300 — \$600 = \$4700

| | |
|---|---|
| Annual charges | |
| Depreciation (10-year life) | \$ 470.00 |
| Average interest | 155.10 |
| Rent (same as *6A*) | |
| Repairs | 60.00 |
| Maintenance | 350.00 |
| Total | \$1035.10 |
| Operating cost per hour | |
| Prorated annual charges | \$ 0.35 |
| Labor (1 man operating 3 machines) | 0.25 |
| Power | 0.10 |
| | \$ 0.70 |

$$\text{Cost per piece } = \frac{0.70}{24} = \$0.029$$

Saving per piece \$0.059 — \$0.029 = \$0.03 or 50 per cent

| | |
|---|---|
| Cost per hour for 24 pieces *6A* | = 1.42 |
| Cost per hour for 24 pieces *5D* | = 0.70 |
| Saving per hour | \$ 0.72 |
| Saving per year | \$2260.00 |

TABLE 3

Machine: *6A* automatic
Subject: 0.35 carbon forged-steel differential housing
Production: 1.33 pieces per hour
Cost of machine and tools, \$4450

| | |
|---|---|
| Annual charges | |
| Depreciation (10-year life) | \$445.00 |
| Average interest | 146.85 |
| Rent (same floor space as *5D*) | |
| Repairs | 60.00 |
| Maintenance | 290.00 |
| Total | \$941.85 |
| Operating cost per hour | |
| Prorated annual charges | \$ 0.31 |
| Labor (1 man operating 4 machines) | 0.19 |
| Power | 0.09 |
| | \$ 0.59 |

$$\text{Cost per piece } = \frac{0.59}{1.3} = \$0.45$$

TABLE 4

Machine: *5D* automatic
Subject: 0.35 carbon forged-steel differential housing
Production: 4 pieces per hour
Cost of machine and tools, \$6050 — \$600 = \$5450

| | |
|---|---|
| Annual charges | |
| Depreciation (10-year life) | \$ 545.00 |
| Average interest | 179.00 |
| Rent (same floor space as *6A*) | |
| Repairs | 60.00 |
| Maintenance | 400.00 |
| Total | \$1184.85 |
| Operating cost per hour | |
| Prorated annual charges | \$ 0.40 |
| Labor (1 man operating 4 machines) | 0.19 |
| Power | 0.15 |
| | \$ 0.74 |

$$\text{Cost per piece } = \frac{0.74}{4} = \$0.185$$

**Saving per piece \$0.45 — \$0.185 = \$0.265 or 59 per cent**

| | |
|---|---|
| **Cost per hour for 4 pieces *6A*** | **\$1.77** |
| **Cost per hour for 4 pieces *5D*** | **\$0.74** |
| **Saving per hour** | **\$ 1.03** |
| **Saving per year** | **\$3090.00** |

new machine installed less the salvage value of the machine replaced. As has been stated before, this may be anything from scrap value to the book value of the machine if applied to some other job.

A direct comparison between the operating costs of the two automatic chucking machines follows:

Tables 1 and 2 compare the two working on a cast-iron fan pulley as shown in Fig. 8. Tables 3 and 4 give a comparison on the 0.35-carbon-steel forged differential housing which is shown in Fig. 9.

It will be noted in Table 2 that the saving per piece amounts to 50 per cent and that the saving per hour to $0.72, thus giving a saving per year of $2260. This particular piece is not one of the best for purposes of comparison, as the material of the work makes it impossible to push the machine to anything like capacity. The 6A machine does not do the grooving operation, this being done on another machine, the operating cost of which should really enter into the above comparison.

In Table 4 the saving per piece amounts to $0.265 or 59 per cent, the saving per hour $1.03, and the saving per year $3090. In the first case with the fan pulley, the machine will pay for itself in a little over two years, and in the second case, in less than two years. This plainly shows that it is economically unsound to use the old-type machine where such a saving can be accomplished.

In closing, the author wishes to acknowledge his indebtedness to Norman R. Earle of the Potter & Johnston Machine Co., for aid and advice in preparing this paper. He also wishes to acknowledge information kindly supplied by the Oilgear Co., the Lodge & Shipley Machine Tool Co., the Acme Machine Tool Co., the Cincinnati Milling Machine Co., and the Heald Machine Co.

## Discussion

F. O. Hoagland.[2] The author refers to the opportunity of disposing of machines. It is to be hoped that conditions in the machine-tool industry will be similar to those in the automobile-tire industry. Tires last 200 per cent longer than they did 15 years ago, but more tires are used than ever before. The foreign market may become a factor again in the machine-tool industry if quality is the watchword.

Anti-friction bearings are being pushed to the front. There is much merit in the movement but it behooves us to see to it that clever advertising does not cause the pendulum to swing too far. High-grade ball and roller bearings are guaranteed to run within 0.0005 in. and how is it possible to true up a piece of work within 0.0002 in. if the spindle is equipped with such bearings? When the load is heavy the antifriction bearings meet the requirements in a highly satisfactory manner, but on precision machinery, where accuracy is required, a well-designed plain bearing is superior.

Statements in regard to the importance of providing convenient means for lubrication are well made. Seventy-five per cent of all breakdowns in machine tools are probably due to lack of lubrication. If a proper oil film is maintained at all times, there never being metal-to-metal contact in the bearings, they should run indefinitely, and with very little friction.

In providing single-pulley drives, the Pratt & Whitney Company did not consider it consistent also to build cone-pulley lathes for customers who wish to cut good threads free from gear chatter marks. The gears in the spindle train are ground after hardening. Cuts can thereby be taken producing results fully as smooth as with an open-belt drive.

[2] Master Mechanic, Pratt & Whitney Co., Hartford, Conn. Mem. A.S.M.E.

The savings in replacing old machines with production tools speak for themselves. It is a case of the survival of the fittest. In preparing statements in regard to comparative costs, it is difficult to get data from the prospective customer as to his present production. Unless these are available, it is very hard to work out a formula. A formula is important and convenient and it should be provided in the printed forms. It is then possible to show the present and the proposed cost and the customer can see the saving very readily.

E. P. Blanchard.[3] The author has brought up the question of the increase of profit per unit. In the automotive industry there is a slogan, "Greater profit per unit," but the salesmen are not sent out to sell the products at higher prices. The industry knows that expansion is over and looks to the machine-tool builder to lower costs.

On the matter of obsolescence, the author also made two very interesting points. Two others were hinted at by Mr. Morrow[4] but were not entirely discussed. First, is the demand of the use of machine tools for certain facilities that are not available in any existing machine. If this requirement exists, every existing model is obsolete, and some live machine-tool builder must build equipment for this purpose.

Another point is especially important here in New England. Mr. Hoover pointed out the necessity for a flexible production program. That means flexibility in machinery and in machine tools and adaptability for the work for which they are intended. Therefore standard machines are far more flexible than single-purpose machines, and obviously of wider use, and naturally it is this type of machine to which New England must look for flexibility. There must be flexibility in cost, flexibility in quantity, in the nature of design, in the ability of the machine to cut metals, and finally in answering the market demand, for today business is not merely manufacturing. It cannot be kept separate from marketing. Quality of work produced is often directly established by the machines, and there is a matter of obsolescence in some machines that should be taken care of.

As far as the use of alloy steel and lubrication is concerned, it was not so long ago that I pointed out in an article in the *American Machinist* that out of 59 machines installed recently in one shop, three were equipped with acceptable lubrication.

The technical press and other forms of advertising can do a better job in some respects than the machine-tool salesman. Those who have had some experience on the road know that there is a barrier to that personal contact, and that the greatest resistance to machine-tool sales comes at a point beyond where the personal contact stops, where the salesman's efforts are blocked. The only way to get over that barrier is by machine-tool advertising. As much information can be given in an advertisement, in a catalog, and in other printed literature that can be put beyond that barrier, as the purchaser requires, for usually higher executives are men who, if the idea of a machine is presented to them with a hint as to how it can be applied, have brains enough to work out the application themselves, or at least see enough of the advantages to delegate some one else to work out the specific proposition in which they might be interested.

Another point in the economics of machine tools is a glance into the future. We have talked about relative quantities and mass production. If we talk about automatic machinery and the advantages to be gained by it, the greater economies, etc., that is all true, always in relative stages. We are ready to admit that the

[3] Advertising and Assistant Sales Manager, Bullard Machine Tool Co., Bridgeport, Conn.

[4] See Shop Equipment Policies in Representative Plants, L. C. Morrow, a paper delivered at the same meeting of the Society, *Trans.* MSP-50-7.

single-purpose machine on one job that is going to run indefinitely is the machine to have, and that flexibility and changeability in application of machinery is necessary for the smaller producers. Every stage of quantity production from the jobbing shop to the mass-production plan will justify a certain refinement in machine-tool equipment and accessories which go with it. Beyond that is a point of diminishing returns which the investment cannot afford. Let every man who is equipping for a certain volume buy equipment suitable for that peak for which he has planned his production, and a little beyond to allow for possibility of expansion, and he will then get all the advantages that could accrue to him in the quantity which he is manufacturing. Machine tools will be designed not entirely for mass production but for all of the intervening stages down the line, and that complete line of machine tools is what I can see not so far ahead.

EARLE BUCKINGHAM.[5] In figuring depreciation on a machine should the total amount credited to the depreciation fund be equal to the original investment, or should it be more?

In a small steel foundry in the Middlewest there was a ten-ton cupola. At the end of a period of years when the cupola had practically served its useful life and the reserve fund for depreciation had amounted in actual cash to little more than the original cost of the furnace, the owners were faced with the necessity of buying larger and more expensive equipment than that which was being scrapped because it was no longer economical to operate the smaller equipment. Should the original calculation for depreciation have been sufficient to cover the changed conditions at the time of replacing the equipment?

C. R. BURT.[6] The question of depreciation is a factor which must be considered more and more by manufacturers and it is possible that during the next few years they will find it necessary to write off their equipment over a period not to exceed ten years, and in many cases over a period of five years. Proper reserves should be set up to place the company in a better position to weather storms, take care of dull periods, and provide for new equipment and the replacement of obsolete equipment. This is primarily due to the fact that we are living in an age of speed and new developments, and no one is prepared to say what we may be forced to face in the line of increased production requirements five years from now.

There may be a misunderstanding in regard to the automotive industry's scrapping machine tools, and while it is a fact that they do expect a new machine to pay for itself within one year, this does not mean that the machine should be scrapped at the end of that period.

Machine-tool builders are alive to the necessity for providing proper lubrication, and during the past two years there has been a remarkable improvement made in developing new lubricating systems.

In regard to figuring cost, it is obvious that no one system will apply to every case, but the important point to get across is that the users of equipment must figure their costs accurately. It is a sad fact that many firms do not figure true costs and do not realize the necessity for installing up-to-date equipment in order to make a reasonable profit.

We are all convinced that the up-to-date manufacturer is going to spend more time in the future in investigating modern up-to-date machinery as well as improved methods. The best-equipped factories with the best personnel are the ones that are going to survive in business over the next few years.

THE AUTHOR. The machine-tool builder is in a fix. He is asked to furnish standard machines which will pay for themselves in increased production in a comparatively short time. Several concerns require that this shall be done in two years, others in five, and others specify no definite time. Of course special machines are required to pay for themselves in a much shorter time. Consequently the machine-tool builder must spend a lot of money in engineering development, and instead of increasing sales he is cutting down sales because if he puts out a machine that will do twice as much work as the former he will sell only half as many. This cuts down production and makes it absolutely necessary to make a profit on a small-production basis.

If machine-tool users who require the machine tool to pay for itself in two years would scrap that machine at a fair interval after the two years and buy a new one, it would be all right. However, at least one concern having such a policy has running in its shops today machines which were obsolete twenty years ago. The conclusion to be drawn from this is that the machine-tool user must gradually reconcile himself to the spending of more money for machine tools.

[5] Assoc. Prof., Engineering Standards and Measurements, Massachusetts Inst. of Tech., Cambridge, Mass. Assoc-Mem. A.S.M.E.

[6] Vice-President, General Manager, Pratt & Whitney Co., Hartford, Conn. Mem. A.S.M.E.

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# The Prerequisites of Successful Polishing

By BRADFORD H. DIVINE,[1] UTICA, N. Y.

*The author discusses those conditions which must be obtained in the polishing department to procure the highest quality of work with the least cost of material and wages. The most important consideration in successful polishing is the glue used in bonding the abrasive to the wheel and its treatment. The next most important consideration is the selection of the abrasive. These are discussed in detail. Other important factors are: the design of the article to be polished, relation of operations preceding polishing, absence of vibration, housing of the polishing department, polishing machines, automatic polishing, and polishing tools.*

THE TERM "polishing," as it is used in the metal-finishing industry, is a misnomer. Strictly speaking, the term should be applied only to those operations which produce luster. As a matter of fact, in the industry it is applied to three distinct processes—flexible grinding, polishing, and buffing. In this paper, however, the term will be used in its commonly accepted meaning.

Flexible-grinding processes are those employed for the reduction of metal where only bright, clean, or smooth surfaces are desired; or as the base for luster or for plating, painting, enameling, or other finishes. Polishing, to use the term correctly, is the process employed where luster only is desired, usually following flexible grinding. Buffing is also a process where luster only is desired, usually on plated surfaces or on non-ferrous metals. Both flexible grinding and polishing processes employ flexible wheels with abrasives glued to them, while buffing operations employ only buffing wheels impregnated with buffing compositions as the abrasives. In the final analysis all three processes are simply varying degrees of grinding.

Polishing is a very old art, dating back to the Stone Age; and, while it has become one of the largest and most important departments of metal manufacture, it has not been developed along engineering lines as have other departments. It has been, with some exceptions, a matter of rule-of-thumb, tradition, or just plain habit or ignorance.

The industry, in general, is in a state of chaos. Costs are altogether too high, mechanical operations are often performed in a crude and inefficient manner, and standardization is conspicuous by its absence. One of the most prominent men in the polishing industry in England, whose company has been in the business of manufacturing polishing equipment for more than one hundred and fifty years, wrote to the author a short time ago: "Polishing is one of the things which have developed from the experience of the workman rather than through scientific investigation." As a result, we have an industry in which engineers and executives have, until recently, manifested little interest.

Dr. Hutton, head of the British Non-Ferrous Metals Research Association, in discussing this question recently wrote as follows:

> For some reason or other, most manufacturers in the metal industry over here seem to be much more keen on devoting time and money to developing other sections of their manufacture, and the polishing room is left as the "Cinderella" of the works. Whereas, of course, it is one of the most expensive factors of production in many manufacturing plants, and would yield great economies if properly brought up to date.

Under present conditions when the executive or engineer seeks information on polishing, he usually runs into difficulties. If he tries to get information from the polishers, he is likely to encounter a smoke screen. He is brought to the realization that the polisher's job has been to polish, not to record statistics or set standards, and that polishing foremen are more interested in getting out production than in studying the science of polishing.

The experiences of two engineers, as recently stated to the author, is typical of what is found when information is sought on polishing problems. One, connected with a concern well known for its efficiency methods, was delegated to standardize the polishing department. After spending some time in the department, he was obliged to report that he was unable to find a point from which to start. The other, an engineer prominent in the brass trade, accepted a commission to provide an industry in France with standard processes for finishing a certain metal, thinking his experience in brass would provide the data. He soon found his mistake. He then searched the libraries of universities and engineering societies for textbooks on the subject. He found absolutely nothing.

There are no textbooks, no recorded information generally available, and no standard terminology in the industry. Even encyclopedias and dictionaries contain little information, and some of them do not even use the words, "polishing" and "buffing."

The subject, "The Prerequisites of Successful Polishing," comprehends the entire problem of the equipment, tools, materials, processes, and standardized control of the polishing department. The points to be considered in this paper are:

1 The design of the article to be polished
2 Relation of preceding processes to polishing
3 Absence of vibration
4 Housing the polishing department
5 Polishing machines
6 Automatic polishing
7 Polishing tools
8 Abrasives
9 Glue.

## Design of the Article to Be Polished

Polishing begins in the drafting room. Wheels of large diameter are more economical to use than wheels of small diameter. The article to be polished should be designed, therefore, to eliminate all unnecessary projections, depressions, angles, recesses or reverse curves, which can be polished only with narrow or small wheels at excessive costs. Usually the cost of any extra metal involved can be more than offset by the saving in polishing.

## Relation of Preceding Processes to Polishing

The polishing department receives the work in either rough or tooled condition. When castings are to be polished without previous operations, they should be as free as possible from excessive sprues, ragged edges, lumps, or other similar surface defects. With forgings, as much scale as possible should be removed by pickling or other methods. In drawn or stamped work deep drawing marks or scratches caused by imperfect dies should be eliminated by correcting the dies. Work which is tooled, or which is ground on solid wheels, should be so processed that the surfaces will not be too rough. Deep tool or grinding marks necessitate the removal of too much metal to reduce the entire surface to the level of the bottom of such marks.

Work should be delivered to the polishing department in such

[1] President, Divine Bros. Company. Mem. A.S.M.E. Fellow, Royal Society of Arts, London.

Presented at the First National Meeting of the A.S.M.E. Machine Shop Practice Division and the New Haven Machine Tool Exhibition, Mason Laboratory, Yale University, New Haven, Conn., September 6–9, 1927.

condition that it will not be necessary for that department to correct the errors of other departments. The cost of correction in the polishing department usually exceeds the cost of correction in the department where the incorrect condition originates. There is often continual strife between the polishing and other departments on this point, whereas care in planning would prevent such conditions. This is one of the underlying causes of the high cost of polishing.

An example of what can be done to help polishing by a study of previous processes is the experience of an ax factory. The forged ax when it left the dies was true to contour, but with an extra thickness of metal to allow for grinding off the scale. The solid-grinding operation to remove the scale destroyed the contour and left the surface in scallops or waves. It required at least three operations, which should not have been necessary, to restore the contour and prepare the surface to take a polished finish. The installation of a cheap and simple process for removing the scale while the metal was red hot eliminated the solid grinding and several polishing operations, and greatly reduced the cost of finishing.

### Absence of Vibration

The absence of vibration is necessary for successful polishing. A polishing wheel, like any high-speed unit, is susceptible to vibration. A vibrating wheel makes scatches which cost time and money to remove. A polishing wheel works at best efficiency only when the entire face of the wheel comes in contact with the article being polished at every revolution of the wheel.

Vibration comes from several sources—the building, the machine, or the polishing wheel. The building may be of light construction, or the floors may be too light to provide a sufficiently rigid foundation for the machine. The machine may be too light, or not well designed. It may not be properly secured to the floor, or may not have the necessary rigidity in the column, the shaft, or the bearings. The polishing wheel may be of such a type, or may be so designed, that it is difficult to balance. Then, too, the wheel may be so headed that high spots or hard spots are developed, which throw the wheel out of balance.

Fatigue of the operator is another reason for eliminating vibration. The author was approached by a polisher in a local plant in which had been installed wheels of a type which ran much more smoothly than those previously used. The polisher said that the vibration from the old wheels caused such lameness in his arms that he was used up by two o'clock in the afternoon. At the end of the day, he was completely exhausted. The new wheels, having no vibration, enabled him to work with less fatigue, and he could enjoy his evenings with his family. Moreover, he was making more money on his piecework rate.

While the vibration in this instance arose from the wheel, it may be assumed that the effect would have been the same had it been due to other causes.

### Housing the Department

The building housing the polishing department should be of solid construction. Floors should be heavy so that polishing machines may be firmly fastened to them. Rooms should be well lighted so that the operators can critically inspect their work. The department should be clean, both for sanitary and mechanical reasons.

There is no reason why the polishing department should be treated as "the Cinderella of the works," as Dr. Hutton says. Conditions in this respect are, however, improving; but many polishing departments are still to be found in basements or other unsuitable places. The idea seems to be that polishing is such a dirty business that the location of the department makes little difference.

Good dust-collecting systems should be installed in order that the dust from the wheels may be quickly removed. Abrasives will fly from the wheels; and if the grains from the coarse wheels come in contact with work undergoing finer operations, deep scratches will be caused which oftentimes the operator cannot account for. It costs money to take these scratches out.

### Polishing Machines

Rigidity and durability are the factors of greatest importance in polishing machines. The items which enter into these factors are the size of the machine, its weight, the floor area of the base, the design and construction, the size, the location and type of bearings, and material in the shaft and its diameter.

Rigidity, preventing vibration, has a direct bearing on the efficiency of the machine and the cost of the polishing done on it. This is not always evident until it is analyzed, but the following experience shows it to be true.

A concern establishing a polishing department bought the best electric belt-driven machines it could find on the market. After using them a while, trouble developed, and it decided to build some machines of the same general type as those purchased. After the machines were constructed, comparative tests, made by the same operators using the same wheels on the same class of work, showed that the new machines enabled an operator to produce from 12 to 20 per cent more work due to the absence of vibration.

Another factor that enters into the question of rigidity and durability in machines is that, with improved glue handling methods, peripheral speeds of from 7000 to 10,000 ft. per min. can be used, requiring a better class of machines than those used a few years ago when peripheral speeds rarely exceeded 5000 ft. per min.

Another question of considerable importance in polishing machines is that of variable speeds. This is particularly true in buffing machines. All buffing wheels, and a great many polishing wheels, wear down in diameter. They operate, therefore, at a constantly reduced efficiency, due to decreased surface speeds. The most common form of direct-connected, electric-driven machine is that using alternating current which, of course, operates at a fixed speed. Direct current, permitting the use of variable-speed motors, is found in only a few localities. To transform alternating current to direct current has been found to be too expensive to be generally satisfactory.

The best answer to this variable-speed question seems to be the machine with the electric motor built into, or attached to, the column of the machine and belted to the wheel shaft. This type of machine is rapidly replacing all others where variable speeds are necessary.

Another form of variable-speed machine recently introduced uses bevel gears, in which, by changing the gear ratio, variable speeds are secured.

### Automatic Polishing

Automatic polishing is rapidly taking its place in the industry for processing large productions of flat pieces, or pieces having a portion of their surfaces flat such, for instance, as the flat parts of pliers; or such articles as plane blades, flat-irons, monkey and pipe wrenches, sheet metals, strip steel, flat bars, knife blades, and any work which is flat or practically so.

While, at present, interest in the automatic polishing of flat work predominates, round bars, tubes, and contoured pieces are also being successfully produced on automatic machines. The variety of work capable of accomplishment by automatic processes is rapidly increasing.

Automatic polishing is not, however, as simple as many people have thought it to be. Many conditions arise not present in

hand work, for the machine is without the human "feel." The work and the wheels are in fixed positions in relation to each other, and the machine cannot correct imperfections in the work as the hand operator can. It is necessary that the work be brought to automatic machines in better condition for polishing than for hand work. Flat work must be absolutely flat, and it is often necessary to straighten or flatten work before polishing.

The difficulties encountered in automatic polishing are not so much in the machines as in the lack of ability of the operators in charge of them to tool them and operate them properly. The wheels must be manufactured especially for the work. Wheels of different character than those used for hand work usually are necessary. Absolute trueness and perfect balance are essential. The wheel must contain within itself the characteristics and qualities which will take the place of the human "feel" in hand work.

The heading of the wheels is a problem requiring much more expertness than in hand work. The head must be as strong as possible to avoid too frequent wheel changes, causing stoppage of production. Provision must be made for keeping the wheels cool, for the almost continuous application of work to the wheel generates much more heat than in hand work.

That automatic polishing reduces costs and speeds up production is shown by the following examples. On one automatic machine, hot-air registers 40 in. square are being solid-ground, flexibly ground, and polished ready for enamel (a ten-wheel operation), in 5 min. and 40 sec. each. On another machine 2400 flat-iron bottoms per hour are finished—one every $4^2/_3$ seconds. In another case 3500 small flat pieces per hour are turned out by one man operating three machines. In the steel trade a ton of cold-rolled sheets 36 × 60 in. has been polished, one side at a time, in 38 minutes.

An interesting effect of automatic machines on the polishing problem was illustrated by an experience in one factory where operators were turning out 175 pieces per hour by hand, claiming that was their limit. An automatic machine was installed with a guaranteed production of 500 pieces per hour. It did as guaranteed, and then the polishers said they could do as much as the automatic machine did. It is not likely that operators on other work in that plant continued to retard production.

## Polishing Tools

A tool usually has some particular characteristic and quality which enables it to perform an operation better than some other tool. When a tool wears out it must be possible to replace it with an identical one. Like all other tools, there is one best polishing wheel for every operation.

Polishing wheels, unfortunately, have been considered and purchased altogether too much from the standpoint of merchandise; and the fact that they are tools of very considerable importance has been somewhat lost sight of. In the manufacture of polishing wheels, too much consideration has been paid to something to sell at a competitive price rather than to the development of the tool itself in the proper relationship to the work it is to do. The general theory has been that anything round, which will yield, and provide a cushion on the face, and to which abrasives can be glued, is a polishing wheel.

The function of the wheel is to act as an agent for carrying the abrasive, and to provide the necessary cushion so that the wheel may properly execute its cutting function. The wheel should be perfectly round and true in order that the entire surface of the face of the wheel may be cutting at every revolution. A wheel which has high spots on it, or is uneven on the face, will present only a part of the abrasive head to do the cutting, with the result that the operator has to employ more time to reduce a given amount of metal—and time as represented by operators' wages is the most costly item in the whole operation of polishing.

Polishing wheels may be separated into three general classes varying according to their characteristics and adaptation to the different flexible-grinding or polishing operations, grading from the coarsest grinding to the finest finishing operations. One class is that in which the wheels are made in disk form, the materials commonly employed being disks of leather glued together; disks of canvas sewed or cemented together, or held in position by metal side plates; disks of woven felt sewed or glued together; disks of sewed buffing-wheel sections, each section individually sewed, and then the sections either sewed or glued into the unit of the wheel, or held together by side plates.

Another class of wheels is that which may be designated as the "crosswise" type. This class of wheel has steel or wood centers around which are placed blocks of leather, canvas, felt, or other materials, the blocks lying radially to the axis of the wheel and crosswise of the face. This position of the material is diametrically opposite to that in the disk type of wheel.

The third class is the wheel with a solid one-piece face. The leather-covered wood wheel is the commonest type of this construction, although leather strap faces are used on solid paper wheels or as a covering for the crosswise type of wheels. Solid felt and solid walrus wheels come in this class of solid-faced wheels.

In general, the disk type of wheels are used for the roughest, coarsest grinding operations. The crosswise types of wheels are more commonly used for practically all operations from the coarsest grinding to the finest finishing, depending upon what the degree of coarseness and what the degree of fineness is. The strap-faced wheels are, or should be, used almost entirely for the finishing operations which produce the lustrous or mirror finishes, or on flat work.

In considering the type of wheel to be used comes the question of the shape of the piece to be polished. A piece which is curved will require the softer types of wheels either of the disk form or the crosswise type. If the piece is flat, all of the operations may be performed to better advantage on the crosswise or strap-faced wheels. There are, however, very many degrees of gradation in these questions, upon which the selection of the proper type of wheel is based. It is impossible to attempt to cover the many phases of the question in this paper.

The selection of the proper character of wheel also requires consideration of the cost of using the wheel. It is characteristic of all wheels of the disk form that the face wears out of shape, and also that the wheel wears down in diameter. Where a flat piece of work is operated upon with a disk form of wheel, it frequently is necessary to true the face of the wheel, reducing its diameter, in an effort to keep the face flat. With this reduction in diameter and lessened surface speed, the element of time is increased.

In wheels of the crosswise type there is less tendency for the wheel to wear down. The fact that the pieces of polishing material are across the face of the wheel, and are not disks, prevents the wheel from wearing in ridges. Such wheels often remain practically full size and in a condition almost as good as new for many years, whereas the wheels of the disk construction are constantly worn out and replaced.

With the strap-faced form of wheel, while the body of the wheel may remain practically full diameter, it is necessary to replace the leather strap frequently.

Wood wheels with the leather strap faces are made in layers to prevent warping and splitting. Such wheels, unless the wood is thoroughly seasoned and set, commonly expand and contract unevenly in the different layers, causing ridges on the face. It is difficult to keep any wood-block wheel round and true.

The amount of cushion in a polishing wheel is a very important

factor in the polishing operation. The amount or degree of cushion in a wheel is secured either by the use of different materials or by the manner in which the materials are arranged in the wheel. The object of the cushion is to permit the face of the wheel to flatten and cover as much area on the work as possible, to grind away as much metal as possible at each stroke, and to provide a smooth cut. The degree of cushion also has a decided effect in securing the finished surface desired.

For the classes of work for which the disk wheels are more commonly used, such as the rough grinding of agricultural tools, the exact degree of cushion is not so essential; but for hardware or other work requiring well-finished surfaces, the proper degree of cushion is highly essential. On some classes of work density is such an important factor that a difference of one degree will render a wheel too hard or too soft for a particular operation.

In wheels of the disk or the solid-faced types, the range of densities is quite limited, usually to three degrees: hard, medium, and soft. In the crosswise types the range of densities is much greater. In some types it is possible to secure as many as eight degrees. In this type also it is possible to regulate the density to a much more accurate degree than in other types, and this type also permits the exact duplication of density when replacing or duplicating wheels.

A factor in wheel economy is the diameter and width of face of wheels. It is advisable to use a wheel as large in diameter as the article being polished will permit, in order to secure the maximum contact of the wheel with the work necessary to remove the greatest amount of metal at each stroke.

Large wheels have less tendency to heat than small wheels. Heat is generated only at the point of contact between the wheel and the work. On the large wheels the heated area has a greater opportunity to cool before returning to contact with the work than would be the case with smaller wheels.

It is also advisable, where possible, to use a face much wider than the piece being polished in order that the piece may be moved about on the face of the wheel and not wear the head in one spot.

The use of wheels of large diameters and wide faces reduces the investment in wheels because of the smaller number required. It reduces the cost of caring for wheels, and of reheading them. It also reduces the time lost by operators in changing wheels.

If time permitted, it would be interesting to follow out the details of the wheel question—the treatment of new wheels, the application of the preliminary sizing coats, the number of them, the manner in which they should be applied; the application of protective coats of heavy glue placed upon the sizing coat and preparatory to receiving the working head; the different kinds of heads, the methods of applying them to the wheel; the uses of the rolled head and the paste head; the number of coats of abrasives; the dressing off of the old head after it ceases to cut; the manner of handling the wheels in wheel drying rooms; the characters of the various processes for coarse grinding, fine grinding, glazing, coloring, greasing out, and oiling and other similar questions. Any one of these phases of the question would provide enough material for an entire paper of itself.

## Abrasives

The abrasive grain, which does the actual cutting, is one of the two most important prerequisites of polishing. Glue is the most important, and the grain is secondary only because the grain cannot be given a chance to do its best work unless firmly bonded to the wheels by the glue.

There are two kinds of abrasive grains in common use—emery, which is a natural product, and grains which are manufactured from bauxite.

Emery is impure or low-grade corundum containing magnetite or hematite. The corundum is that portion of emery which does the cutting. The other materials are inseparable from the corundum particles; they have no function in the cutting operation, and tend to modify the cut of the emery. This modification of the cut is considered by some to be advantageous in the finer operations employed for the actual production of luster. For flexible-grinding operations, the manufactured abrasives are far superior to emery.

Examined under the glass, the manufactured grain appears very much like sharp pebbles, uniform in size, and containing no foreign matter. It differs from emery in being more uniform in hardness or temper. Each grain is so constructed that when properly bonded to the wheel it will fracture away piece by piece, each fracture presenting a fresh cutting edge until the grain is consumed. Wheels headed with manufactured abrasives have less tendency to glaze than those headed with emery.

Care should be taken in selecting manufactured abrasives to see that they are free from slivers or elongated grains which would scratch the work.

Manufactured abrasives are treated to provide capillarity in order that the glue may grasp them firmly. In the storage of them it is important that they be kept free from moisture which might tend to deteriorate this capillarity and weaken the glue bond.

A great many concerns have been unable to secure as satisfactory results with manufactured abrasives as with the natural emery. The difficulty was not due to the grain itself, but entirely to the use of inferior glue, or to improper glue handling equipment and methods. The manufactured grains are harder than emery, and, therefore, require a stronger bond.

Care must be used to see that the proper sizes of grains are used in the proper sequence from the coarser to the finer operations. For instance, in certain cases where a No. 46 grain may be followed by a No. 80 grain, the gap between the grains may be too wide, and a much faster reduction of metal would be secured by following the No. 46 by a No. 60 or No. 70. If the gaps between the grain sizes are too great, the effort of the operator to reduce the metal by increased pressure against the wheel to make it cut, often burns the ridges, causing discoloration. Then, too, the coarse ridges have a destructive effect upon the wheel head of the finer abrasives following.

One of the evidences of the wastage caused by the improper bonding of the grains to the wheels is the fact that a business has been made of reclaiming abrasives, which have been torn bodily from the wheels, resizing and selling them. This on the face of it may seem like a good thing; but a little thought will show that, had the grains been properly bonded to the wheels and consumed by fracturing away in the polishing operation, as previously described, there would be no necessity of a reclaiming process and no grains to reclaim. Where the grains are torn from the wheels through improper bonding, and not reclaimed, they are, of course, wasted.

Another important feature in handling grains is the proper consistency of the glue for the different sizes of grains. If the glue is too thin for coarse grains, it will not provide the proper body to hold the grains. If the glue is too thick for the finer grains, the cut of the grains will be modified, a glazed condition of the wheel face will result, and wastage occurs. As in other conditions when the wheel ceases to cut freely, the inclination of the operator to force the wheel by excess pressure is likely to burn the metal, to require extra time for an operation, and to soften the glue on the face of the wheel (which in itself decreases the cutting ability of the abrasives), and the whole process becomes destructive and expensive. Researches are now being made to determine the correct consistency of glue for the different sizes of abrasives.

### Glue

Glue is the most important prerequisite of polishing. When it is realized that the abrasives glued to polishing wheels have to perform practically the same operation of grinding away or tearing down metals as solid vitrified wheels do, it will be evident that glue as the bond between the wheels and the abrasives is the most important factor in polishing. The efficiency of the combination of the wheel and abrasive as the cutting tool depends almost entirely upon the strength of the glue bond. The ability to secure the desired finished surface, and the cost of securing that surface, depend upon the strength of the glue bond. In fact, glue is the keystone of successful polishing.

The reduction of the processes of glue handling to a definite formula has been one of the most important steps toward the standardization of the polishing industry. However, to utilize such a formula to the best efficiency, the glue, handling equipment, and all factors pertaining to it, must likewise be standardized.

In spite of the fact that the use of glue in the mechanical arts is traceable over 3300 years, the use of glue seems to be little understood. One glue manufacturer has stated that with the consumption of 80 million pounds of glue annually, he doubts if 20 per cent of those using it have the vaguest conception of what glue is, or how it should be applied. The author would go farther and say that not three men out of a hundred in the polishing industry have a proper conception of what glue is or how it should be applied. Also, the influence of glue and glue processes upon polishing operations and costs is little recognized.

Every pound of glue wasted through inefficient methods carries with it a considerable wastage of abrasive grain. A recent experience showed that by simply changing the process of using glue, the same amount of work was produced with one-half the quantity of glue and abrasives. Going farther, the right kind of glue reduced the quantity again so that the same amount of work was produced with from 20 to 25 per cent of the glue and abrasives originally required. In other words, by using standard processes w h the proper glue, four and five times as much work was produced from each wheel head.

Glue is commonly purchased on a price basis rather than on a quality or performance basis. If price alone is to be considered, the basis of comparison should be the cost per quart of liquid glue ready for use. Glues of the better qualities will take more water to the pound of dry glue than glues of inferior qualities, resulting in a lower cost per quart of melted glue. The price of glue, generally speaking, is indicative of its quality.

The higher grade glues have greater strength, and are better adapted to polishing than glues of lower grades. However, the strength of glues of higher quality can only be brought out by proper handling methods. Ordinary processes of glue handling often reduce the strength of high-quality glue to that of inferior glue. The author has actually seen 30-cent glue so reduced in value by the handling processes that it gave no better results than a 10-cent glue.

The glue which gives the most satisfactory results for polishing is the best quality, first-run, straight hide glue. The characteristics necessary are jelly strength, toughness, viscosity, and—what is more important than anything else—flexibility. Many glues set hard and brittle, and are broken up and torn out by the bending action of the face of the wheel.

The first step in organizing a glue department and standardizing glue processes is the arrangement and equipment of the glue room, which should be entirely separate from the polishing department. Glue is a rather delicate thing to handle. It is easily affected by either high or low temperatures. The glue room should, therefore, be arranged so as to be free from drafts which would chill the glue. Windows when open should be equipped with deflectors. Doors should be on double-swing hinges to remain closed constantly.

The glue apparatus, and in fact the whole glue room, should be kept as clean as a dairy. Glue brushes, when not in use, should be kept in a weak solution of carbolic acid in order to destroy the bacteria which may accumulate in them.

The glue heater should be of a type which will furnish a constant supply of fresh glue in its strongest condition. Glue should be mixed and used in small batches so that it may be consumed in four hours from the time it is melted. Otherwise, it deteriorates rapidly. The individual glue pot should be of a size, therefore, to contain only a four-hour supply of glue.

The multiple-pot system is preferable to the large single pot. The size and number of pots should be such as to provide for the different consistencies of glue required for the different size grains, and also to allow extra pots for hot water and for sizing. Aluminum is the best material for the glue pots on account of its property of holding heat, and the ease with which the pots may be cleaned.

The glue heater should be equipped with a thermostat to maintain the glue at a uniform and correct temperature. Thermometers should be provided to check up the temperatures. Psychrometers should be provided in order to determine, when wheel heads do not last, whether the trouble is due to softening the wheel head by humidity or to some other cause.

Ovens should be provided to heat the wheels to 120 degrees. The abrasive troughs should be provided with heaters to heat the grain to the same temperature as the wheels to prevent chilling the glue.

In addition to the glue handling equipment, the glue room should be equipped with an accurate device for balancing the wheels each time after they are headed. The room should also be equipped with tools for removing the residue of old wheel heads. Water should not be used for this purpose when it can be avoided.

The wheel room should be separate from the polishing department. The partitions or walls should be arranged with openings both at top and bottom to permit a rapid circulation of air to carry away the moisture evaporated from the glue while it is setting. The temperature of the wheel room should be that of the working departments. Artificial heat should not be used, nor should the wheels be chilled. Both of these practices have a very detrimental effect upon the strength of the glue bond. Nature will take its own time in setting the glue, and it must not be interfered with.

There are two elements in glue handling which must be recognized and controlled. One is heat, the other is bacteria.

Heat makes glue, and heat destroys glue. The maximum strength of the glue bond, which enables it to resist the frictional heat generated in polishing, is secured only by a proper control of heat in the preparation of the glue.

Glue loses five per cent of its strength for every hour of heating. Laboratory tests have shown a loss of 67 per cent of strength after 12 hours under heat. Tests of a high-grade glue, made by the United States Forestry Bureau, showed a loss of one-half the glue strength in seven hours at a temperature of 176 deg. fahr. Glue is in its strongest condition at a temperature of 135 deg. fahr.

In order to secure certain definite results from the preparation of glue, certain definite procedures must be followed. Glue is somewhat like a chemical in that a slight change in the materials or in the formula used will make a considerable difference in the results obtained.

The conversion of dry glue into liquid glue of the strongest character is made by adding certain definite proportions (by weight) of either pure or distilled water to the glue, soaking it a

definite time, and melting it by raising the temperature to about 135 or 140 deg. fahr. Different makes and qualities of glue require different proportions of water.

Ground glue should be soaked in cold water at least three hours; flake glue, eight hours; and cake glue, twelve hours. After the glue is soaked it does no harm if it stands twenty-four or even forty-eight hours, providing the temperature of the room is not over 70 deg. fahr.

The glue when placed in the heater should be melted, not cooked or boiled.

To secure the different consistencies of glue required for the different sizes of abrasive grains, hot water should be added to the liquid glue. The proper consistency, once determined, should be recorded by instruments and standardized.

In applying glue to the wheel, no draft of air should come in contact with the glue brush, for instant chilling and serious weakening of the glue will result. The wheels and abrasives, having been heated to at least 120 deg. fahr., will then allow the whole mass of abrasives, glue, and the wheel to cool gradually without detriment to the glue strength.

Glue hardens in the process of setting much as concrete does. Setting begins with the cooling, but continues long after the cooling has reached its stopping point. A wheel head may be cold in an hour or so, appearing to be ready to use. As a matter of fact, a minimum of 48 hours is required to complete the natural process of setting glue to its maximum strength. The process of setting is, of course, the evaporation of moisture from the glue.

It is altogether too evident that very few people appreciate just what is taking place in the process of preparing and applying glue to polishing wheels. The idea seems to be to spread on the glue, apply the abrasive, and, as soon as the wheel is cool, start cutting metal with it. The usual result is extravagance, inefficiency, and waste.

The author has seen wheels headed up with a paste head $^1/_4$ in. thick, and within fifteen minutes used for grinding away metal. This was exhibited by a man who had been a polisher for 45 years, and who took pride in his so-called expertness in handling wheels.

A fact not apparently well known is that glue handling is a fight with bacteria, and again the question of heat comes in. Glue chemists tells us that the bacteria increase rapidly, consuming the strength of the glue, at temperatures higher than 140 deg. fahr. This is recognized in the manufacture of glue, which is cooked at temperatures of about 140 deg. fahr., and then the temperature is reduced as quickly as possible in the process of solidifying the glue to the point at which the bacteria become virtually inactive.

This is the reason why everything in and about a glue room should be kept as clean as in a dairy. The bacteria in glue which is left over night will contaminate fresh glue the next morning and decrease its strength probably 50 per cent. Bacterial action is one of the reasons why glue loses its strength either under prolonged heat or at temperatures above 140 deg. fahr.

One of the abuses in the use of glue has been the use of formulas for improving the glue, such formulas containing alcohol, dry carbonate of white lead, precipitate of chalk, and glycerine. Such formulas are entirely worthless. Another idea in common use in certain parts of the country is that the addition of a certain "gum" to glue will increase the strength of the glue bond. Analysis showed that the "gum" was nothing but wheat starch containing coloring matter to disguise it. Glue chemists tell us that there is nothing that will increase the strength of glue except Russian isinglass, the strongest adhesive known. Its cost is so high, however, that its use in the polishing trades is prohibited.

In addition to the points considered in this paper, there are two other prerequisites of successful polishing. One is the correct methods of processing the various polishing operations; the other, the supervision and standardization of the polishing department. However, to discuss the many points involved in the numerous and varied kinds of operations, and the use of those prerequisites already discussed in the execution of them, is not possible in the time allowed for this paper.

As to the supervision and standardization of the polishing department, the author's observation of the industry, both in this country and abroad, has convinced him that it is to the advantage of executives and engineers that they analyze their polishing problems; that they do not try to correct conditions by remedying the weak spots, but by making a complete and fundamental analysis as a basis for a systematic control and standardization of polishing departments.

## Discussion

ROBERT T. KENT.[2] In the very last paragraph the author says: "It is to the advantage of executives and engineers that they analyze their polishing problems; that they do not try to correct conditions by remedying the weak spots, but by making a complete and fundamental analysis as a basis for a systematic control and standardization of polishing departments." There can be no question but that the author is absolutely sound in this statement. At Bridgeport we have a considerable polishing problem, and we are running into difficulties all the time. Probably the cause of many of the difficulties is that we have been trying to remedy the weak spots instead of making a study of the fundamentals of polishing.

The author has outlined nine variables which may affect the polishing problem. Each one of those variables can be subdivided into a great many others, so that if the advice that is given in the last paragraph of this paper is to be followed, the problem involved will be an enormous one. Industries which have large problems in polishing can well afford to take this advice and start an investigation into the fundamentals of polishing and the standardization of our problems.

H. E. BOOTH.[3] Will the author make clearer what he means by the supervision and standardization of the polishing room? Each room is so different and each polishing shop is so different from the others that the standardization of one does not seem to have any relation to that of another.

THE AUTHOR. That question can be answered only in this way. Standardization should start with each department in regard to its own particular methods of work. The industry cannot be standardized. For instance, Mr. Booth's plant manufactures cutlery. It is almost impossible to standardize the ways and means of polishing cutlery. Oftentimes two concerns will use successfully different speeds, different abrasives, and different sequences of abrasives. The question is, which is standard? Each individual concern has to study its own problems.

What is meant by standardization is starting from the forge room or the foundry and following the work to see that the operations preceding polishing are so standardized in relation to it that this operation, which is the most expensive in the factory, is not unduly loaded with cost. That is one phase.

The other phase is more particularly the standardization of wheels to determine the density of wheel necessary, the speed at which it should be run, the kind of abrasive which should be used, and the methods of putting the abrasives on. One

[2] Bridgeport Brass Co., Bridgeport, Conn. Mem. A.S.M.E.
[3] Winchester Repeating Arms Co., New Haven, Conn.

method of standardization is to have one man in the wheel room to do this, rather than permitting individual polishers to do it as they see fit.

A. J. Carmichael.[4] The author says that work to be polished by an automatic machine must be absolutely flat. In most of our experience we find that there is no such thing as absolutely flat work. It is impossible, particularly on sheet-metal work, to make parts that are absolutely flat, and there is a question whether it is not cheaper to have the hand polisher who can get around those imperfections go ahead and do the work, rather than pick over parts to get them ready for this machine. How does the author procure flat work, and how does he get it ready for the automatic polisher so that the machine can do the work efficiently?

The Author. The word "flat" is used relatively. Latitude was allowed in the paper by using the phrase, "or practically flat." It has been the custom to send work up to the polishing department in any old condition and expect the polishing to correct it, and with automatic polishing this cannot be done. Usually the straightening or flattening process is a flat stamping process. If the work is a perforated piece which has been bulged so as not to be noticeable to the eye, it may be all right for the purpose for which the part was made, but it is far cheaper to flatten it before putting it into an automatic polishing machine.

F. D. Lane.[5] Has it been the author's experience that with the automatic polisher it is possible successfully to polish a strip of sheet stock as it comes from the rolls of a mill, commercially flat?

The Author. Polishing sheet stock as it comes from the rolls is quite a problem. The constant application of the wheel or wheels to the work generates heat that is likely to burn the metal and glaze the wheel. The problem is still being studied. There are possibilities in it. We have a job on hand now in our concern of exactly that character—safety-razor stock, but this is not being accomplished by headed-up wheels. It can only be accomplished by an abrasive moistened with oil (kerosene usually) and putting it over free wheels—not headed-up wheels.

Ordinary commercial strip stock has not been successfully polished, although I think it can be done.

Chas. F. Schaffer.[6] I should like to defend the polishing foreman. Executives say that polishing costs are tremendous, but they do not realize the condition in which articles come to the polisher.

The engineer should know more about polishing. He should know what it costs to polish an article. It makes a difference whether the article has contours or is flat. It seems to be the impression that work can be sent to the finishing room in any condition and that the finishing room will fix it up. No one seems to realize what this costs. When the engineer designs his work he should have in mind that the finishing department will represent one of the cost items.

H. A. Kirberg.[7] What does the author consider the logical type of polishing machine—one with a sleeve bearing or one with a ball bearing?

The Author. I should say the ball-bearing type. Frankly, all of the polishing *lathes* on the market are altogether too cheaply built. There are very few well-designed lathes. If ball bearings are used, the bearings are cheap ones. But ball bearings are all right if they are properly designed and properly located in the housings.

William Buxbaum.[8] Has the author had any experience with the effect which the length of time it takes wheels to dry has on the inventory in a factory of any size?

The Author. Nature takes its own course. It takes forty-eight hours for any glue to set. If a wheel is properly headed up and has set forty-eight hours, the first thought is that many more wheels will be required, but this is usually found not to be true. Even if more wheels are required, the efficiency of the wheel due to the fact that it has set forty-eight hours is enough to pay for additional wheel equipment.

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# Shop-Equipment Policies in Representative Plants

## Reasons for Discarding Equipment; Time During Which New Equipment Must Pay for Itself; Methods of Buying and Discarding; Faults of Machine Tools; Methods of Drive; Records; Human Equation

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THE TERM "shop equipment" in the metal-working industries properly includes all of the equipment used within the shop; machines, motors, conveyors, small tools, hand tools, transmission units, and so on. It is obviously impossible to treat of each kind of equipment in a paper that will not be unduly long, except as the principles laid down for one class may be applied to the others. It is with machine tools, primarily, that every metal-working shop is concerned, and therefore it is with keeping machine tools up-to-date that this paper deals.

How big is the machine-tool industry? What is its economic importance? The answers to these two questions will indicate the position that equipment policies should occupy in the affairs of users and builders.

The answer to the first question, "How big is the machine-tool industry?" is taken from the United States census of manufactures.

The Census gives certain figures for the value of machine tools, and metal-working machinery produced during 1919, 1921, 1923, and 1925 as follows:

| | 1919 | 1921 |
|---|---|---|
| "So-called" machine tools | $212,400,158 | $67,782,232 |
| Machine tools by "other" establishments........ | * | 1,524,926 |
| Metal-working machinery | 57,541,482 | 19,287,572 |
| Maximum, all products... | $269,941,640 | $88,594,730 |

| | 1923 | 1925 |
|---|---|---|
| "So-called" machine tools | $136,871,096 | $148,598,285 |
| Machine tools by "other" establishments........ | 3,787,527 | ** |
| Metal-working machinery | 56,817,437 | 47,352,746 |
| Maximum, all products... | $197,476,060 | $195,951,031 |

For more conservative figures, deduct the items which are not complete machine tools or metal-working machines:

| | 1919 | 1921 |
|---|---|---|
| "All other products"....... | $32,652,932 | $ 7,319,211 |
| "Parts and attachments"... | * | 8,936,547 |
| "Portable tools"........... | 10,907,928 | 4,480,611 |
| | $43,560,860 | $20,736,369 |

| | 1923 | 1925 |
|---|---|---|
| "All other products"....... | $ 8,571,124 | $24,946,320 |
| "Parts and attachments"... | 25,397,185 | 32,192,602 |
| "Portable tools"........... | 9,312,814 | 11,896,325 |
| | $43,281,123 | $69,035,247 |

* Not given.
** Included in above.

Minimum, complete machines only, $226,380,780 in 1919; $68,058,361 in 1921; $154,194,937 in 1923; and $126,915,784 in 1925.

The minimum figures represent an unknown number of machines, but one sub-division of "machine tools," valued at $137,525,963 in 1919; $41,506,657 in 1921; $70,717,797 in 1923; and $58,334,175 in 1925;[2] represents the following numbers of machines: 163,892 in 1919; 56,675 in 1921; 68,836 in 1923; and 38,855 in 1925. The average value at factory per machine was $840 in 1919; $733 in 1921; $1030 in 1923; and $1506 in 1925.

A word of caution must be said with respect to the average value. It should not be construed that it is comparable from year to year, nor can it be significant as an average price of a machine tool, because lathes, milling machines, grinders, hacksaws, etc., of widely different values are produced in different proportions in different years.

However, the average value, being large (about 1000) shows rather conclusively that no portable and small tools are included as machine tools, and tends to confirm the reasonableness of the figures.

The economic importance of the machine-tool industry cannot be measured by the size of the industry. It is the bit of yeast in the bread that is important—without it the bread would not rise. In answering the second question, "What is the economic importance of the machine-tool industry?" it is enough to say that back of all labor-saving machinery, back of the economical production of every mechanical necessity or labor-saving machine in the world, stand the machine tools that made them possible. Without them we could have no industry as it now exists. There could be no factories for the making of either necessities or luxuries.

Since 1914, while the population of the United States has been increasing 18 per cent, the productivity of the nation has increased 35 per cent, a rate almost double.

The railroads today are carrying 20 per cent more freight than in 1914 with practically the same number of employees.

The farms are producing 35 per cent more in volume of crops with an actual decrease in the number of farmers.

In these thirteen years, the automobile industry has multiplied almost eightfold in the number of cars built per year and over sixfold in the total annual value of the product, yet with a steady decrease in the hours of human labor per car. Whereas in 1914, the average medium-priced car required 1260 hours of labor, today it requires but 220 hours. Yet with all this decrease of human labor, the quality of workmanship per car has steadily increased.

Seven years ago, one man could handle only 800 tons of pig iron per year. Today his capacity is 1200 tons a year. Eight years ago a pair of shoes required one hour and forty minutes of human labor. Today a pair of shoes requires but 54 minutes.

The machine has brought about this advance everywhere in national productivity, this decrease everywhere in the number

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[2] Returns incomplete.

of human-hours or human-minutes per piece, per ton, per dozen, per acre.

In the past thirteen years, over 6500 new metal-working machines and tools have appeared on the market—improvements on old types, new developments, new creations of mechanical genius—all designed to increase output and accuracy, and to reduce upkeep and labor.

It is gratifying that there is a growing recognition of the importance of the machine-tool industry in the economic scheme. An indication of this increasing recognition is the thoroughness with which many large users of machine tools are studying their equipment problems from the engineering and profit points of view. It is true that even in some of the larger plants there still exist hit-and-miss methods of discarding and buying equipment, and that education to substitute definite policies is needed. Likewise in the plants of medium size and in the small shops ideas are not so well defined as they should be. There is a duty to be performed on the part of the machine-tool builders, on the part of the machine-tool salesmen, and, perforce, on the part of the educators of the machinery industries, to supply the deficiency.

The subject of keeping the machine-tool equipment up-to-date falls very naturally into these sub-divisions:

- Reasons for discarding equipment
- Time during which new equipment must pay for itself from earnings
- Methods of buying
- Disposition of discarded equipment
- Faults of machine tools
- Method of drive
- Single-purpose vs. standard machines
- Machine-tool records, especially those of repairs
- Importance of the human equation in equipment policies.

### Reasons for Discarding Equipment

Equipment is discarded because it is worn out or because it is obsolete. Almost all machine tools are made up of several castings proportionately large, with smaller parts of other materials. There is seldom a great amount of wear on the castings, and the deterioration of cast iron is not rapid. Of the parts made of other materials, new ones can be made or bought. Inasmuch as wear upon all parts is seldom uniform, it would seem that if each part were replaced as it became worn the machine would never wear out. Experience proves, however, that there is a relation between the cost of repairs and the cost of new machines, that, if determined accurately, will indicate when expenses for repairs are no longer justified. There are to be taken into consideration the losses due to the non-productiveness of the machines while in course of repair. The repair cost is being maintained by some of the largest users of machine tools. If the plan should be adopted universally much of the ancient equipment now in use would be withdrawn from active service. Moreover, the records of the costs of repairs, used with the records of initial costs, would enable all users of equipment to arrive at sound rates of depreciation.

Obsolescence is brought about by several influences. They are:

- Improvements in the design of machine tools
- Increased output requirements
- Changes in the design of the product of the user
- Elimination of uneconomical manufacturing operations
- Changes in the methods of manufacture of the product of the user
- The effect upon the investment in materials in process
- The effect upon floor space
- The effect upon power consumption.

One manufacturer gives the definition of obsolescence by saying that a machine is obsolete when it will no longer pay the dividends obtainable from some other machine. Another, that obsolescence as applied to productive machine tools is the result of the elimination of uneconomical manufacturing operations. Still another, that a machine tool is made obsolete by the development of the art through which the modern tool produces more than the one it supplants.

Some of the reasons that have been given for discarding equipment and for buying new are:

- Repairs too frequent
- The new machine is a better investment
- Worn out
- Too light for heavy duty
- Machine does away with hand labor
- Cannot afford to waste the time of a high-priced mechanic on a low-production machine
- Difficulty of keeping operator interested in old machine
- Cost per productive hour of operation shows that machine is not economical for the production loaded on it
- There is a constant pressure from the customer for lower prices on the product—a pressure that must be met by lower costs of production
- To secure maximum output with the greatest possible protection of the employee's health and life
- To secure increased production
- To secure better quality
- To reduce the cost of manufacture
- To reduce the items of expense that make up the cost hour
- For manufacturing a new line of apparatus
- To reduce the cost of direct labor
- To reduce the investment in materials in process
- To eliminate the necessity for highly skilled operators
- To reduce the power consumption
- Changes in the design of product
- Changes in the methods of manufacture
- Availability of machines of new design
- To get more out of the dollar invested.

### Time Allotted Machine to Pay for Itself

There arises the question, "How much better than the old must a new machine be?" From the data available it seems that the consensus of opinion is that it must be very much better indeed. The automotive industry is very strongly inclined toward the belief that the new machine must be so much better that it will pay for itself from increased earnings within one year. Other manufacturers, whose products include tractors, ball-bearings, automobile starting, lighting, and ignition systems, universal joints, vacuum sweepers, roller bearings, cash registers, and machine tools, vary from a limit of one year to a limit of several years, say four or five. A railroad repair shop allows as much as six or seven years. One or two refuse to set a limit, taking the stand that each purchase must be made strictly upon the merits of the case. The principal argument advanced to substantiate the claim that one year is the proper limit, is that there are yearly changes in the product manufactured that are likely to make much equipment worthless. No doubt that argument carries weight when special machinery is being considered. So-called standard machines should have more in their favor, especially in view of the fact that the volume of sales of machine tools does not indicate that any immense number of standard tools are written off the books within one year or anything like that period.

Surmise aside, existing conditions call for continual and marked advance in the design of machine tools. Certain it is that the users of machine tools have given the matter serious consideration. They have at times reduced their calculations to formulas

las. For example, one manufacturer uses a formula to say that the number of months in which a piece of equipment will pay for itself is equal to the total of expenditures for the new equipment divided by the total of savings per month. Stated more elaborately, it says that *the number of months in which the equipment will pay for itself* equals *the cost of the new equipment installed* plus *the cost of tooling the new equipment* plus *the cost of interest for X years at 6 per cent* (*X* equaling the number of years determined upon as the maximum time during which the equipment must pay for itself) plus *the cost of depreciation for X years at 10 per cent* plus *the book value of the displaced equipment,* that sum divided by the difference between *the existing rate (or cost) per piece* and *the estimated rate per piece on the proposed new equipment* multiplied by *the number of pieces to be produced per day by the proposed equipment,* multiplied in turn by *the number of working days per month,* to which product is added *the savings in overhead per month.*

In that formula it is considered that the savings are made up of productive labor, and that if the expense of productive labor is cut in half, the percentage of overhead to productive labor is increased 10 per cent. This conclusion is reached as a result of cost determinations, and there is no doubt that it applies in the plant using the formula.

Another manufacturer uses practically the same formula, except that he determines his change in overhead from a "burden control record," that shows direct labor charges; direct burden charges (under which there are 14 sub-divisions); indirect burden charges (under which there are 8 sub-divisions); and fixed charges (under which there are 6 sub-divisions).

These two examples are cited to show to what extent some users of shop equipment have gone to determine on an engineering basis their policies of discarding and purchasing equipment. For the most part they have been left to do these things for themselves, although it might seem quite logical to believe that such definite methods of determining the value of new equipment should have been worked out and presented as sales arguments by the machine-tool builders.

### Buying Methods

There is a definite movement away from the selection of machine tools and equipment of like importance by the purchasing agent or purchasing department. There are exceptions, where the purchasing agent is a man of engineering training or caliber, who could properly be called an equipment engineer. However, in almost all plants of appreciable size, the formal order is issued by the purchasing department, which is responsible also for follow-up. Many times the requests for quotations are written and signed by the purchasing departments. In some plants, where the purchasing department has nothing to do with the acquisition of equipment except the clerical work, it is nevertheless necessary for salesmen to make their overtures to that department, and upon all visits to go through the formality of gaining admittance by applying first to the purchasing agent.

No fault should be found with the arrangement just described where it exists. Each plant has its own problems to solve in taking care of visitors. Where there are many of them some routine must be followed in the interests of the seller and his time as well as the buyer and his time.

Some of the methods of buying with which I have become acquainted are, in brief, these:

*Plant No. 1.* The shop superintendents and master mechanics make their recommendations annually, at a stated interval before the equipment budget is made up. The supervisor of equipment passes on the recommendations. The financial man of the organization authorizes the procuring of data. The purchasing agent obtains proposals. The machine-tool committee selects.

*Plant No. 2.* The superintendents of individual plants, who are responsible for their own equipment, ask for it as they need it. Their requests are sent to the plant managers, of whom there is one for every three or four plants. The plant managers act upon the requests, and send those considered favorable to the general works manager, who authorizes or rejects. An equipment engineer studies all of the requests sent to the general works manager and advises him.

*Plant No. 3.* Recommendations originate with the time-study department. They are approved by the head of that department, by the production manager, and by the factory manager. The equipment is bought on guaranteed production.

*Plant No. 4.* Requests originate with the foremen. They are investigated by the research department and approved by the factory manager. The purchasing department prepares the order, issues it, and does the follow-up work.

*Plant No. 5.* Demonstrators recommend that certain machines be bought. Recommendations also originate with machine-tool supervisors, who make a physical review every three months and report through their superintendents on equipment needed for greater production, to replace less suitable equipment, or to replace worn-out equipment. Action is then taken by the director of works equipment.

*Plant No. 6.* Foremen make recommendations to the production manager. All details of proposals and quotations are handled by the purchasing department. All salesmen are dealt with through the purchasing department.

*Plant No. 7.* The heads of the factory engineering department, tool equipment, and metallurgical department make recommendations for the approval of the purchase of equipment to an operating vice-president. Foremen are consulted by those heads on problems of great detail. Details of ordering and following up are carried on by the purchasing department. Equipment is bought on trial.

*Plant No. 8.* The men who control the acquisition of equipment are the superintendent, supervisors, efficiency engineers, foremen, and job foremen. Any one of these men has the privilege of requesting shop equipment to improve method or product, reduce cost, or conserve floor space. All requests are studied by the efficiency engineering department. The purchasing department obtains proposals and quotations. Formal order is made by the efficiency engineering department. Purchasing department follows up.

*Plant No. 9.* Anyone in the organization has the privilege of recommending the acquisition of equipment. Every recommendation goes first to the "plant committee," made up of leading foremen and superintendents and presided over by the general manufacturing superintendent. Recommendations of this committee go to the "manufacturing committee," made up of the heads of all departments, including purchasing and engineering. The committee's decisions are referred to the board of directors for approval or rejection.

*Plant No. 10.* The production, manufacturing, and methods and tools departments have the privilege of requesting equipment. The works manager decides upon the machines to buy. The purchasing department issues the formal order. In investigating equipment the mechanical man looks to the mechanical details. The purchasing agent looks to the purchasing details. Visiting engineering representatives of manufacturers talk to the foreman, superintendent, or works manager.

*Plant No. 11.* Equipment specialists determine the need for new machinery, development engineers work out new methods of manufacture, and standardization engineers have charge of the replacement of obsolete and worn-out production equipment. The duties of the standardization engineers include the development of machine specifications, assistance to and coöperation

with machine-tool builders, and the development of new models of standard types of production equipment.

*Plant No. 12.* Orders for new and replacement equipment originate in the master mechanic's division. They are approved by the superintendent of production. Purchasing details are cared for by the purchasing department. The master mechanic's division is responsible for obtaining deliveries.

*Plant No. 13.* When machine foreman and department foreman agree that replacement is necessary, they consult the tool supervisor. When the three agree, they consult the superintendent, who makes the decision. Foremen may suggest the make of machine wanted. The tool supervisor issues requisitions, which pass through the hands of the division superintendent, general superintendent, and works manager. The purchasing agent issues the orders.

In connection with the methods of buying, it is of more than passing interest to know what are the sources of the information required by users of machine tools to enable them to keep pace with developments. In the contacts that I have had I have found an almost unanimous agreement upon these sources:

- The new-equipment sections of the technical press
- The advertisements of the technical press
- Machine-tool salesmen
- Machinery expositions
- Plant visits.

These sources speak for themselves.

### How Discarded Equipment Is Disposed Of

Discarded equipment is disposed of by being sold to other users; by being sold to dealers in used equipment; and by being scrapped. As the scale is descended from the high-production shop and the shop working against keen competition, it is found that there is a market for discarded equipment in the shops where not so much is required from a machine and where competitive conditions are not so severe. It is not good economics to throw into the scrap machines that possess a good part of their life and of course they are going to be sold and resold just as automobiles are.

Whether the machines are sold direct to the new users or to dealers in used machinery depends upon market conditions, and the effort that the seller is willing to make to find customers. Evidently there is an economic need for the dealer in used machinery, since he retains his place in the industry.

Among certain users of machine tools there is a policy not to allow discarded machines to stand around for long periods. If there is no market available within a reasonable length of time (about six months) after the machines are taken from the equipment, they are broken up for the scrap. One of the reasons advanced in favor of rapid disposition is that antiquated machines have a bad influence upon shop morale when they stand around. Another is that the floor space is too valuable to give over to them.

### Faults of Machine Tools

In selecting equipment that will give better service and bigger profits, the user of machine tools must, of course, take into consideration what to him are the faults of the machines he is using. There are two things to be desired in this matter of faults: One is that the user would report all shortcomings to the builders and the other is that the builders would give such reports the consideration that they deserve.

Among the faults that have been charged up to machine tools by users who constitute on the whole a very desirable market, as to volume, are these:

- Some parts made of wrong material
- Improper lubrication
- Improper tooling
- Wrong application to work in hand
- Overloaded
- Too wide a range in speed and feed variations
- Cost of repair parts too high
- Repair parts frequently do not fit
- Loose-pulley bearings poor
- Bearings too small to take care of the added load due to dull cutters
- Table bearings and knee slides of milling machines need greater attention
- Locking devices do not lock
- Heavier tables are needed on drilling machines, and more adequate arms needed to support them
- Fly-wheels are needed to absorb shock
- Flexible mounting of driving pulleys would be an improvement. Machines equipped with them would fit into line manufacture whether set parallel or at an angle to the line
- Something should be done toward uniformity of the heights of tables
- Further study of the causes of chatter is needed to improve design
- The master tools of industry should be started in life with greater accuracy
- Some machine tools are built too hurriedly, in order to offset a competitor's lead
- Poor workmanship
- Wrong selection of materials
- Not enough oiling capacity
- Not enough ball and roller bearings
- Present-day multiple-spindle operations require too long a time in indexing
- Slides are too short on some machines
- Punch presses should be heavier
- On some machines collets are too light
- On some machines shear pins should be provided. On others the shear pin should be closer to the work to protect more of the mechanism
- Standard machines are seldom capable of operating at speeds as high as desired
- Punch presses could be equipped with friction wheels to drive against the inside of the rim, and with soft brass wire shear rings between screw and pitman, so that overloading will cause the friction wheel to slip, and double-heading or other interference will cause the wire safety ring to shear.

No attempt is made to justify or deny the faults enumerated. All of them have been named by very earnest users of machine tools.

### Drive

There is a great difference of opinion as to the best method of drive for modern machine tools in modern shops. Individual motor drive and group motor drive with belts from overhead works to the machines are receiving most attention. The method of transmitting all of the power from a single unit by means of line shafts seems to be out of the running.

The proponents of the group drive advance as their principal argument the lowering of the power factor when many motors are running at less than full load. They point also to the greater investment in motors when individual motor drive is the method adopted.

Those who favor the individual drive are inclined to believe that the advantages of the absence of belts, with greater cleanliness and better light, and with accessibility for service by overhead cranes, more than offset any increased costs. They point out

also, that, with group drive, when a transmission line or motor goes out, the entire group is out; that there is much waste when only a single machine or a few machines are run overtime; and that the advantage of the flexibility of the individual drive in positioning and moving machines is of itself a sufficient claim in favor of that type of drive.

To me it appears that each shop must work out the problem for itself, and I point out the situation as a suggestion to the machine-tool builder that the prospective buyer of his equipment may have very good reasons back of his desire for just the kind of drive that the builder is not furnishing, no matter which kind it be.

Favor is sometimes shown the single-pulley drive because machines so equipped are more readily sold as second hand. The fact that electric current differs in different localities is another point in favor of the single-pulley drive.

### Single-Purpose vs. Standard Machines

To some extent the selection of single-purpose or standard machine tools is comparable to the selection of one or the other type of drive. Some manufacturers lean very heavily toward the special, single-purpose machine It is probable that they do so because they find that it pays, even when no such machine is available on the market, but must be designed and built in their own factories. There are others who will almost go out of their way to stick to standard machines. In favor of the single-purpose machine is the fact that it can be shown to pay on work of great volume and of fixed design. On the other hand, the standard machine has greater resale value and does not limit changes in the design of product.

### Machine-Tool Records

The importance of machine-tool records has been brought to my attention. If we agree that plants should be kept modernized, we must agree, I think, that the machine-tool record is indispensable, not alone for cost, depreciation, and inventory purposes, but for carrying a record of the costs of repairs and comparative data needed in dealing with the equipment problem.

In writing of his equipment policies for the *American Machinist*, the factory manager of a famous plant said,

> Our repair cost records serve as a guide as to the time when a machine should be placed in the obsolete class. They serve also as a guide in the matter of rebuilding, of which we do probably more than the average amount. We consider repair costs so important that we budget the payroll of the repair department monthly, projecting the budget three months ahead. The budget is based on productive labor according to our output schedule. When the cost of the repair payroll exceeds the budget allowance, one or both of two things must be wrong. Either our repair gang has not worked efficiently or we are repairing where we should be buying, or both. Since we are able to check our repair labor very closely, we are most likely to find that we are nursing along some machines that we should be better off without.

### The Human Equation

One of the advantages of up-to-date machine equipment is the effect upon employees. It is only human nature to want to live in a modern house, to own an automobile with the latest improvements, and to want to work with the latest equipment. I was told recently in a big and comparatively new shop where there are none but individually motor-driven tools, that when the men were moved from an old shop, with older methods of drive, into the new one, some of them said that they grew six inches.

It is not uncommon for managers or equipment engineers to believe that there is a noticeable increase in production when new and modern equipment is used, due to its effect upon the morale of the operator and entirely aside from increase due to the greater productivity of the equipment.

It seems quite possible, as has been explained to me, that there is a psychological effect upon men of the movement of materials, for example, on conveyors, and for that matter, on rapid-production machines, that induces an ambition to maintain the movement, or even to accelerate it.

Modern machinery has taken much of the onerous heavy labor from the backs and hands of the workmen. Power rapid-traverse mechanisms have eliminated the heavy and time-wasting cranking formerly necessary to elevate cross-rails and to traverse heads and tables. Improvements such as push-button control have reduced danger to both machinery and men and have saved much time formerly wasted. Proper and complete guards have greatly reduced the hazards of machine-shop work, have saved much suffering and much money. Convenient controls have added to the day's production and have made it possible for the operators of the heaviest machines to leave the shop after a day's work still comparatively fresh. These improvements, inherent in up-to-date equipment, have benefitted machine-tool-building and machine-tool-using industries greatly because of the increased satisfaction of the shop personnel.

These facts are being recognized, and with that recognization there is a growing appreciation of the value of the opinions of the men in the shop concerning equipment. Usually expression of shop opinion is secured from the foremen. More and more wide-awake concerns are giving their foremen a voice in the selection of equipment. A large concern, to which I have referred previously, has gone so far as to insist that all recommendations for equipment must originate with the foremen of the plant. To follow such a policy does not mean that the superintendent, or the manager, or the president, need sit by and wait until the foremen have discovered needed equipment. It does mean a tactful plan for getting the foreman to sell himself in regard to that equipment and finally to recommend and request it.

Where high-production programs are in operation there are two methods of introducing new machine tools into the production. One method is to put them into the line as soon as received and the other is to try them on a production basis in an experimental department. The choice of method depends upon the type of management and the type of operators. It is needless to say that the experimental method is necessary in some shops, and there is much in its favor even when not necessary, especially if the man who is to operate the machine is allowed to help put it through its experimental paces. Prejudices that exist in the shop can be overcome by proper management, which includes the introduction of new equipment in a way that allows for existing conditions. Perhaps the fact that prejudice exists is not often enough recognized. However, most machine-tool builders will probably believe that it has existed if they will recall an experience with some machine that was thoroughly proved in the builder's shop yet could not make guaranty for the buyer.

### Conclusion

In conclusion there are several interesting facts that seemed to have no place in the paper up to this point as it is sub-divided.

In the matter of loading machine tools there are two policies followed: One is to load them well within their rated capacities; and the other is to give them all the load they will stand. Without going into great detail, the reasons for underloading are to secure long life with a minimum of maintenance and repair expense. The reason for crowding, or overloading, is to get out of the machines all the production they can deliver before they become obsolete. The overloading is done with full expectation of shorter life and higher repair costs.

An instance of the profit accruing because the overloading policy was followed came to my attention. The introduction of a single change in the method of making a part caused the replacement of 300 of one type of machine by 30 of another, for the same

output. It is quite a task to dispose of 300 machines of one type in the second-hand market, and in the case cited the manufacturer's consolation was that while the machines were in use he had made them much more than pay for themselves by loading them to capacity.

Replacement of machines by groups is many times advisable. Especially is this true in piece-work departments, where a new or improved machine tool would give one operator an advantage over the others.

Machine-tool salesmen as a whole receive the praise of some buyers and the adverse criticism of others. What seems to be certain is that most users of machine tools, of the type that understands the equipment problem, want real engineering service in selling. Expressed very succinctly, what is wanted is a kind of salesmanship that will have as an objective, before everything else, the interests of the buyer.

The last point is that automatic operation and feeding are growing in favor. The magazine is preferred to the hand feed where applicable, and the hopper feed, where the parts can be shoveled in, is preferred to the magazine. The limits to the magazine and hopper feeds are recognized, of course. However, their use is increasing, and must be taken into consideration.

There is more to the equipment problem than I have told. There is a great deal more that I do not know. I have been glad to contribute what I could for two reasons: To help bring to the attention of those users of machine tools who are not keeping their equipment up-to-date those instances in their plants where the judicious spending of money on new equipment will pay them a profit; and to help to uncover for the machine-tool builder those opportunities for sales that are hidden because of the failure of that division of management responsible for equipment to understand the possibilities of the machinery available to reduce its costs.

## Discussion

F. O. Hoagland.[3] The author called attention to many interesting and cold facts. Prior to the War machine-tool production amounted to about, $50,000,000 per year. This was thought to be an enormous figure, but comparing it with the figures which the author gives, it seems rather insignificant.

The period of obsolescence for a standard machine tool is very indefinite; it may be written off in ten years; a special machine, in three years. There are cases where a machine must pay for itself within a year because the product may be changed. It is chiefly important, however, to keep the machine busy earning profits, otherwise all calculations come to naught. A machine running, say, 30 per cent of its capacity because it can turn out in that time the required amount of product, will require three or four years in which to pay for itself, whereas if it could be used nearer 100 per cent of the time it would not only pay for itself in a comparatively short time but in a few years it would show a handsome profit running into several times its cost.

The various methods of buying new equipment are probably working well enough under various shop organizations and conditions. It is hard to say which one is the best. I think it depends on the individual and on the requirements.

From both the buyer's and the seller's point of view, however, it is essential that the salesman, in order to be successful, know his line. It gives confidence to the prospective customer and closes the order for the machine to mutual advantage.

A short time ago we were in the market for a certain kind of machine. There was one machine which was particularly attractive, but there was one operation required of the machine which had not been done before and there apparently was no reason why it could not be done. The manufacturer's representative, however, thought that it could not be done. Before the representative got in contact with headquarters and found the operation could be performed on the machine, the order had already been placed with another concern. If the representative had known the possibilities of his machine and had been willing to fight for it he would have received the order.

The present tendency is definitely towards individual motor drives. For some time to come, however, the single-pulley drive meets the requirements as it is applicable to lineshaft drive also and can be easily converted either way.

[3] Master Mechanic, Pratt & Whitney Co., Hartford, Conn. Mem. A.S.M.E.

H. S. Beal.[4] One of the interesting things that we discuss with our customer sometimes is the amount at which a man should be capitalized when replaced by a machine tool. In our minds we arrive rather loosely at the figure of $15,000 per man. Any machine which can be purchased inside of $15,000 and thereby eliminate one man appears to represent a proper saving.

J. H. Connolly.[5] There was mention in the paper of equipping power presses with friction drives with shear rings between screws and pitmans. The shear rings in the screws have proved not so attractive on small presses because the continual pounding of the press causes the ring gradually to shear through until, after some continuance of that action, it finally lets go under very light load. A somewhat brittle washer might be used that would break under an excess of load instead of gradually shearing through.

The installation of motors on either new machines or old machines in service may be somewhat simplified by the use of belt-tightening attachments which are now readily furnished. They are mounted on the motor and if the machine is built for an ordinary belt drive the motor can be easily installed and connected to it.

Charles F. Marquis.[6] The policy of the General Electric Company in regard to the replacement of tools is to put a machine tool on the retired list when it is found to be unprofitable. It is either sold or scrapped. Very frequently a new design alters the plant equipment and makes a machine unfit for the particular purpose for which it was furnished. Lists of these retired tools are sent to the different plants, no matter where they are located—Erie, Ft. Wayne, Pittsfield, Lynn, or Schenectady. Any machine out of use in any one of the plants is put on the list, and the executives from any of the other plants can select any of the tools if they have a use for them.

As Mr. J. A. Smith, who has charge of the machine tool purchases in Schenectady said, "We have no sentiment about machine tools. If they are not profitable, we take them out and either sell them or scrap them." In his organization there is one man who is delegated to try to dispose of these machine tools. If he does not find a purchaser within a reasonable length of time, the machine is scrapped. It is all purely a matter of dollars and cents, and if profitable use cannot be made of a machine tool it is put out of commission.

Industry, of course, is changing very rapidly. First we are particularly busy on one line, and when we get equipped for that, something happens to the sales organization and it does not get the orders, or perhaps there is a lull in that line and another branch will come up, and then of course the tools are taken wherever they are applicable.

[4] Assistant General Manager, Jones & Lamson Machine Co., Springfield, Vt. Assoc-Mem. A.S.M.E.

[5] Standard Machinery Co., Providence, R. I.

[6] General Electric Co., Schenectady, N. Y.

# Recent Developments in the Application of Anti-Friction Bearings to Machine Tools

## Illustrations of a Variety of Designs; Importance of Proper Lubrication and Methods of Preventing the Accumulation of Dust in Bearings

By R. F. RUNGE,[1] NEW YORK, N. Y.

THE SUBJECT of this discussion is rather far-reaching, if consideration is to be given to the numerous details entering into the proper application of anti-friction bearings. Due to limited time, it will be quite impossible to deal directly with specific details, and the discussion will therefore be confined to general principles.

It does not seem necessary to repeat here the fundamental practice in connection with anti-friction-bearing application, as that has been covered very completely in previous discussions and in the vast fund of information which has been widely distributed by the several leading ball-bearing manufacturers. This discussion will therefore deal with the newer developments with which there has now been sufficient experience to permit recommending them as proper machine-tool practice.

These principles may best be understood by referring to several illustrations which treat of the more important machine-tool elements. Certainly, anti-friction bearings have very definitely proved their superiority over other types of bearings in the more usual applications, such as change-speed gear boxes, loose pulleys, back shafts, feed screws, drilling-machine spindles, etc.

To those in the machine-tool industry who were pioneers in the application of anti-friction bearings many years ago, considerable credit is due for breaking down many of the old prejudices. This has resulted in a very decided advance and change of opinion during the last two years throughout the industry, so that we find today many important applications of anti-friction bearings in locations which only a short time back were considered questionable. The result obtained required considerable improvement in material, character of finish, and closer tolerances, accompanied by considerable metallurgical and physical research and also experience gained through actual use in the field, so that a surprising advance has been made over a short period.

It is desirable first to understand the improvement which those interested in this development are attempting to attain. Anti-friction bearings, to be successful, must show many times the life of the older forms of bearings or considerably less maintenance, resulting in greater number of productive machine hours. The application must be one which is more foolproof than the older types of bearings, where a scraping-to-fit is necessary or adjustments are required. This is becoming more and more important as a greater amount of unskilled labor is finding its place in industry.

The next item of importance is the use of a bearing which has the absolute minimum of friction. This is quite obvious, as friction means wear, and wear definitely defeats accuracy and quantity of production. In this connection, it is unquestionably a fact that the more modern types of ball bearing, made to extreme accuracy and of the highest quality of material, will certainly provide the least friction, and for the same reason require the minimum or no adjustment.

Heat also is directly coupled with the subject of bearing friction. Heating on precision machines is of decided importance, as it will be immediately understood by those who are closely engaged with machine operations on precision work that such machines do not produce close tolerances consistently until the machine has attained its operating temperature. This materially affects machines in which automatic gaging of certain forms is used, so that machine heating due to friction in bearings plays an important part in percentage of scrap production.

If the above elements are realized through the application of anti-friction bearings, then it must necessarily follow that there will be a power saving of some magnitude, or, on the other hand, a greater amount of power delivered to the cutting tools, resulting in increased production.

It can therefore be considered, in general, that the advantages of anti-friction bearings have been classed here in the order of their importance and may be summed up as providing for greater production at less cost.

Rigidity is highly desirable in most machine-tool applications, thus reducing to a minimum the possibility of vibration. In that connection it might be well to mention here that an attempt has been made, in the more recently designed machines, to provide heavier machines for a given operation, and in many cases where vibration has been present experience has shown that additional weight in the parts affected has very successfully overcome that objection. Mention is made of this condition for the reason that ordinarily the bearings are criticized for unsatisfactory results, whereas in many cases the trouble may be elsewhere.

In order to obtain proper results, it is necessary very carefully to analyze the conditions to be met with regard to the bearings as with any of the other machine elements. It is therefore most earnestly recommended that any one contemplating the use of anti-friction bearings should have the entire problem very carefully studied by the bearing manufacturer. The several high-grade bearing producers have had considerable experience, and full advantage should be taken of that experience.

The machine-tool manufacturers have been most cautious in the past in considering the application of anti-friction bearings to such parts as milling-machine spindles, lathe spindles, grinding-wheel spindles, and work-head spindles on the various types of machines. This is to be expected due to the requirements of consistent accuracy of performance and also due to the failures of past years, when the bearings had not been developed to as high a standard as at present, and improper types as well as improper mountings were used. This discussion will therefore be confined to the more important machine-tool-bearing locations, and an attempt made to indicate the more modern methods of application which are proving to be most satisfactory.

### Some Applications

Fig. 1 shows the application[2] of ball bearings to a geared-head lathe. The important consideration here is the spindle mounting. On the chuck end of the spindle there are two pairs

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Presented at the First National Meeting of the A.S.M.E. Machine Shop Practice Division and the New Haven Machine Tool Exhibition, Mason Laboratory, Yale University, New Haven, Conn., September 6–9, 1927.

[2] The patent rights of this and other designs illustrated in this paper are protected.

or four bearings recommended. The use of four bearings provides for maximum rigidity of the spindle and sufficient bearing capacity with the minimum outside diameter and maximum spindle diameter for sufficient torsional strength. Two bearings are used at the back end of the spindle, where the load is lighter. This mounting gives the maximum of rigidity and, the accuracy of all parts being held to very close tolerance, is sufficient for load

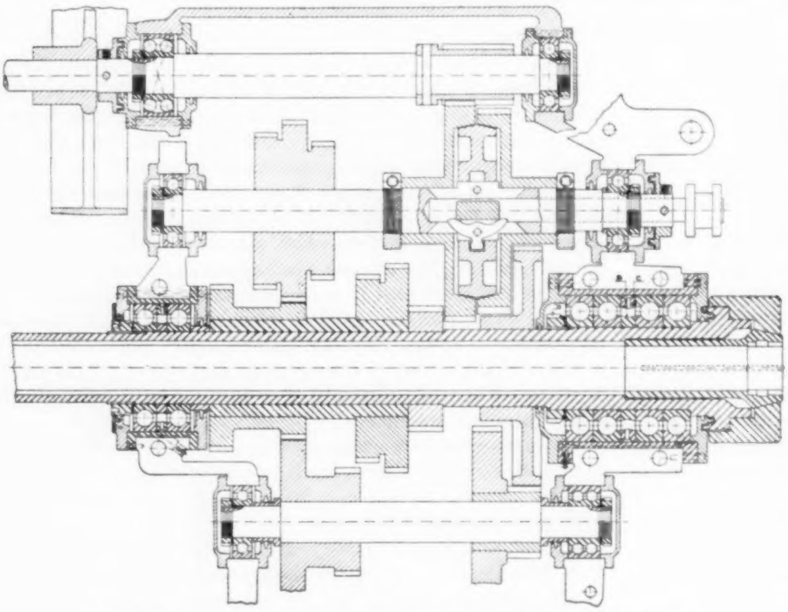

Fig. 1 Application of Ball Bearings to a Geared-Head Lathe

distribution over the several bearings. In order to permit greater accuracy in the finishing of the parts, attention is directed to the mounting of the outer rings of the bearings in a bushing. The bushing permits the use of better material for supporting the outer rings of the bearings, and may be hardened where this is an exceptional requirement. In this type of application, it is always recommended that the bushing be ground in order to provide closer tolerance for fitting and a higher character of finish. The use of bushings will further permit through-boring for both the front and back holes in the headstock in one setting, and adds further to the ease of assembling by the use of capped bearings.

Where it is found in the assembly that the spindle does not line up with the ways of the lathe, the use of the bushing permits the scraping out or reboring the bushing seat for proper alignment, and the outside diameter of the bushing can then be ground to suit the changed hole diameter.

It is obvious that it is necessary to eliminate all radial and axial play in the bearings, as well as in the fitted parts composing the bearing mounting. It is also necessary to confine the amount of movement permitted by elastic deformation between the balls and the raceways when the load is applied. This is provided for in the individual bearings, so that when the locknut $A$ is set up, the bearings are loaded both axially and radially by establishing the proper amount of elastic deformation within safe limits to a point beyond the amount of elastic deformation set up by the working load. The axial and radial movements in the bearing under the working load are therefore held to extremely close limits, which is only a small percentage of the amount that must be provided for in an oil-film-supported bearing, with which it is always possible to change the position of the spindle by squeezing out part or all of the oil film. In the case of the ball-bearing mounting, the variations imposed by an oil film can be absolutely ignored. It is only necessary to grind spacing rings $B$ and $C$ to a slight difference in width, due to the accumulated variation between the widths of the outer rings and the widths of the inner rings. The individual bearings are interchangeable with each other, are reversible, and can be individually replaced. It might be added that spacing ring $B$ is necessary to lock all of the inner rings between the nut and shoulder. Spacing ring $C$ is used for the transference of thrust load from one set of bearings to the second set, so that there will be more than one row of balls carrying the thrust or axial load.

The four bearings comprise a unit definitely clamped on the spindle and in the housing, thereby positively stabilizing the spindle

The bearings in the auxiliary shafts in this lathe head are more or less general as to type of application. A possible exception to that may be pointed out through the use of the self-aligning type of ball bearing next to the pulley. This design permits the bearing to accommodate itself to any possible deflections due to the overhung belt load.

The spindle mounting is one which is also recommended for precision machines of the centerless, cylindrical, and horizontal surface-grinding types.

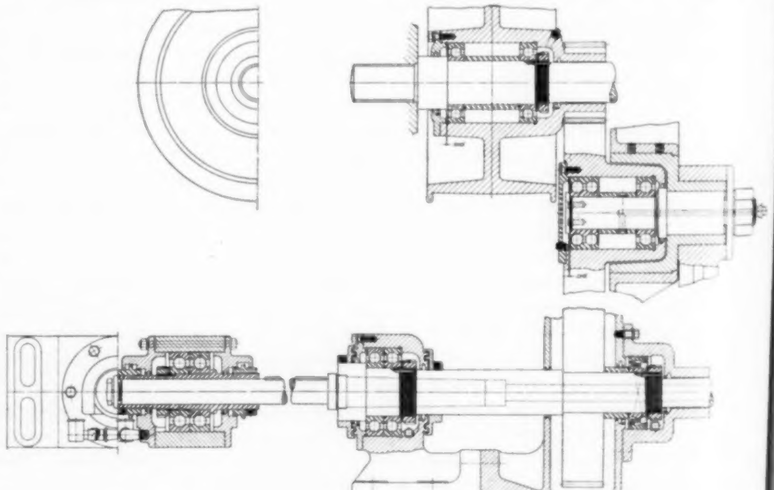

Fig. 2 Application of Ball Bearings to a Milling Machine

Lubrication is an important feature which will be covered later.

Fig. 2 shows a design which applies to horizontal milling machines, the important element of which is also the spindle. In this case, the main spindle is supported on two bearings at the front end and a self-aligning bearing at the back end. The arbor support also carries two bearings. In both of these instances where two bearings are used, the same principles of bearing construction are embodied in order to provide for initial elastic deformation between the balls and raceways. Attention

is called to the construction of the arbor support, wherein the mounting can be removed without exposing the bearings or interfering with the lubrication. Although this design does not include bushings for holding the outer rings of the bearing, this is desirable for the front end of the spindle when space will permit.

On the intermediate gear there is shown a double-row, deep-groove ball bearing which comes directly under the tooth load, and a single-row bearing at the back end, principally for more rigid stabilization. The idler pulley is the usual type of mounting with regular single-row bearings. It may be pointed out here that four different types of bearings are used, which are composed of extremely accurate spindle ball bearings, self-aligning ball bearings, double-row deep-groove ball bearings, and single-row ball bearings, each of the types having been selected very definitely to perform a particular function.

Figs. 3*a* and 3*b* show two types of live tailstock centers for lathes and similar uses. Fig. 3*b* incorporates the usual type of flat-plate thrust bearing to withstand heavier thrust loads than can satisfactorily be carried on any of the radial types of bearings. This thrust bearing is required to carry the load in one direction only, as indicated by the arrow. When the tailstock is without load, it is important that the stationary ring of the thrust bearing be prevented from dropping, and for this purpose a series of light springs (marked *A*) are provided in the backing plate to keep a slight reverse pressure on the bearing.

It will be noted that the spherical type of roller bearing is

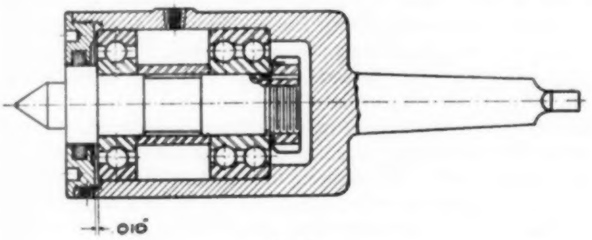


Fig. 3*a*

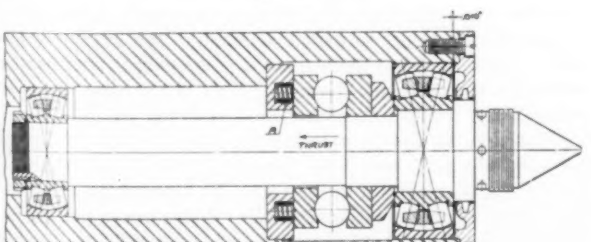


Fig. 3*b*

FIGS. 3*a* AND 3*b* APPLICATION OF BALL BEARINGS TO TWO TYPES OF LIVE TAILSTOCK CENTERS

introduced in this construction. This is for the purpose of obtaining greater bearing capacity within a limited space. It might be noted that this type of bearing has slightly more than twice the capacity of the equivalent size single-row ball bearing.

Fig. 3*a* shows a live tailstock center employing one double-row ball bearing to take the combined thrust and radial loads and on the front end a single-row bearing for radial load only. The advantages of these designs are that there is less heating set up than with dead centers, that there is a slight reduction in power required, and that there is an almost entire elimination of redressing of the center points, permitting more accurate positioning of the work, as the centers can be brought up metal-to-metal.

Inasmuch as there are many lathes, milling machines, etc., equipped with simplified countershafting, the design of Fig. 4 is recommended as one which provides for maximum efficiency, minimum space requirements, minimum weight, and minimum attention. While there is nothing particularly new about this application, attention is called to it as in many cases a very inefficient type of countershaft is supplied with the machines, and if maintenance and power saving are to be considered in the machine tool itself, they are equally important in the countershaft.

The designs so far presented have dealt mainly with moderate

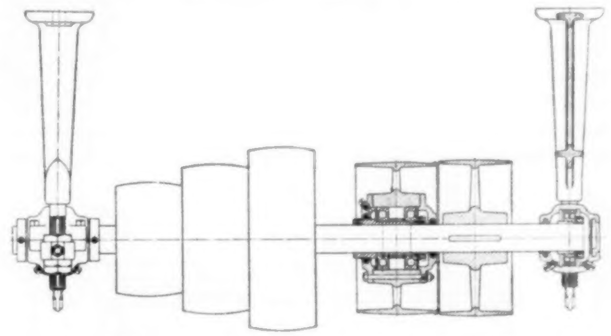

FIG. 4 COUNTERSHAFT EQUIPPED WITH BALL BEARINGS

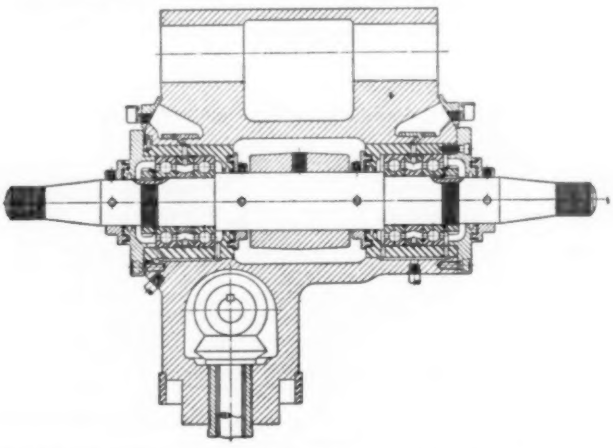

FIG. 5 GRINDING-MACHINE SPINDLE EQUIPPED WITH BALL BEARINGS

speeds and comparatively high load. In the grinding machine the conditions are generally reversed, speed being the most important consideration and load conditions secondary.

The mounting shown in Fig. 5 is for a grinding spindle for external work. In this it will be noted that the bushing principle is again used. This provides for greater accuracy of bearing mounting, which is of still greater importance where higher speeds are encountered. The same special type of spindle bearing is recommended in this design. Here, again, where load capacity is not so important, the use of two bearings at each end of the spindle is recommended.

Fig. 6 shows a small high-speed internal grinding spindle. Due to the great amount of trouble which has always been experienced with sliding bearings on high-speed work, ball bearings came in for earlier consideration on this application than elsewhere, and there has probably been more experience and greater progress made on the internal spindle than on any other type. Where a few years ago these spindles were operated at about 10,000 r.p.m., speeds of approximately 25,000 r.p.m. are now being regularly used, and in certain unusual cases from 50,000 to 60,000 r.p.m. are being attempted. In these higher speeds there are

several important considerations aside from the bearings, but without proper bearing application, any other developments, such as high-speed drives, etc., are of little consequence.

Fig. 6 shows again the double-bearing mounting at both the front and rear ends of the spindle, utilizing specially made spindle bearings. The pair of bearings at the front end are locked endwise in order to stabilize the spindle, and it probably does not require mentioning that the stabilizing bearing should always be located nearest the grinding wheel so as to keep to a minimum the amount of change of wheel position due to expansion of the spindle because of heat. While this principle applies particularly to grinding spindles, it also is of importance on any other type of spindle. This design then permits the expansion or contraction of the rear end of the spindle, as the two bearings at this point are permitted to float axially. Due to the special spindle-bearing construction, the two bearings in this design may also be locked through the inner races by a nut,

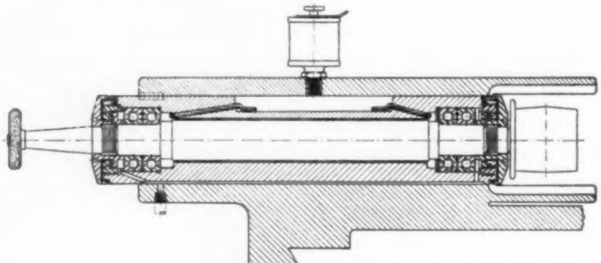

Fig. 6 Grinding-Machine Spindle Equipped with Ball Bearings

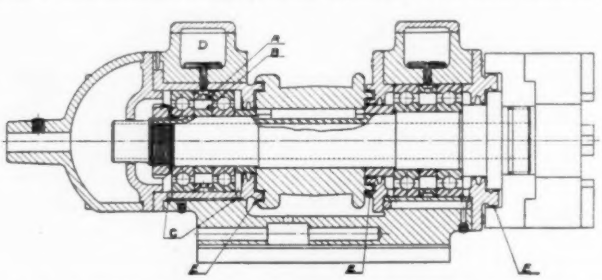

Fig. 7 Application of Ball Bearings to Work-Head Spindle of Grinding Machine

thereby taking out all of the radial and axial looseness and providing for the amount of initial elastic deformation.

The reason for providing for initial deformation in bearings for high-speed grinding-spindle mounts is somewhat different than for those on the heavier spindle applications. In the high-speed internal spindle it is not only necessary to eliminate any play from the bearings, but, due to the high speed of the balls in the raceways and very quick acceleration, it is important that the balls be not allowed to skid on the unloaded side of the bearings. When initial elastic deformation is provided for in the bearing, each ball is definitely driven through the inner race by positive contact. This skidding which takes place in the bearing will naturally set up a slight amount of wear, thus causing looseness.

Fig. 7 is a rather interesting application in view of the fact that for many years it had been considered quite undesirable to attempt to carry the work-head spindle of grinding machines on ball bearings, the general objection being that, due to the slow speed of the work spindle, any eccentricity or irregularities of the bearings would be transferred to the work being ground. The method of mounting as shown in this design, in consideration of the accuracy of the special spindle bearings, completely overcomes that objection and is responsible for even more accurate work than has been generally done on spindles having sliding bearings, as here again the variation in oil film in the sliding bearings is completely eliminated. This construction follows closely those shown previously in so far as bearings and mountings are concerned.

## Lubrication

Proper lubrication for ball bearings is important, although it is commonly known that they require a very small amount of lubrication. It is quite necessary, however, that that be of proper consistency, and care should be taken to use a lubricant free from acids and foreign matter.

There have been certain tendencies toward the use of grease in precision and high-speed applications. Grease may be used under certain conditions, but due to the great variety of viscosities of grease, and also the numerous fillers which are used, grease lubrication is subject to a wider range of variation than is oil and is therefore less controllable. For such applications as have here been discussed, years of experience have very definitely shown that oil lubrication is preferable.

In the design shown in Fig. 7, as well as in most of the others, it will have been noted that oil lubrication is provided for in that oil is fed to the bearings through wick filters. It is a very common occurrence in supplying additional lubricant for machines in operation in the shops, that the end of the oil can may contain a certain amount of grit or chips; and in the case where grease is used, many times the grease has picked up, through exposure, considerable gritty foreign matter. It is rather surprising to note the amount of fine grit which will settle into an open grease can from the atmosphere. A small amount of abrasive which finds its way into the bearings is likely to develop bearing looseness due to abrasion. This is usually misconstrued as bearing wear, which it is in a sense, but not inherently due to the bearing itself. The filtering of lubricant before it enters the bearing housing has very definitely been proved a decided advantage, and on that basis alone grease is eliminated as a proper lubricant as it is not subject to efficient filtration.

As has been mentioned in a previous paragraph, it is advisable on precision machines to reduce as much of the heating as possible. Where grease is used, there is grave danger of generating additional heat through churning. This is also true where the bearings are partly submerged in a reservoir of oil. This is eliminated in the designs presented, in that the oil is fed through the wick as a filter and from there through the spacer ring *A*. Part of the oil may find its way into the bearing through capillary action along the internal surface of the spacer ring *A*, but most of the oil will drop on to the spacer ring *B*, the result of which is that most of the oil entering the housing is atomized. A reservoir is not permitted to form, as the oil will feed through the bearings and out through drain holes *C*. This really develops into a drop feed from oil reservoir *D*, as the feed through the wick is easily controlled. This has an additional advantage in that should any foreign matter or abrasive find its way into the bearing housing, there is a tendency for the oil to carry it out through the drain holes. In certain instances where capillary feed is advisable, the wick is permitted to rub on a rotating part, which not only acts as a wiper for additional oil suction, but also for atomizing.

Where automatic lubrication, or a centralized system, is used for all of the bearings on a given machine, this same principle of lubrication can be applied.

This principle of lubrication cannot be too strongly emphasized, as foreign matter and improper lubrication in any type of bearing are extremely injurious, as has well been demonstrated.

From the standpoint of foreign matter getting into the bearing

housing, the design of enclosures is of equal importance. In the design in question, at the three positions $E$ is shown what is termed a labyrinth seal. This may be of the single or multiple type. Those shown in Fig. 7 are single, whereas those shown in the design in Fig. 6 are multiple. This construction has proved quite satisfactory, although there still remains room for improvement. In the case of high speed, grooves filled with felt, cork, or other compositions have not proved entirely satisfactory. The rubbing friction is sufficient to burn the material, and, in addition, any soft material acts as an absorbent of abrasive, and over a period of time sets up a lapping condition, accompanied by heat and wear.

In closing, the importance should again be emphasized of making a careful analysis of the conditions to be met in the various types of machines; that full advantage should be taken of the information the bearing manufacturers are in a position to supply, and that standardization should be definitely kept in mind. It is fair to say that the initial installation of ball bearings, if made standard practice on machine tools, should show very little, if any, higher cost than many of the present types of sliding bearings, to say nothing of the decidedly lower maintenance costs of ball bearings in comparison.

The machine-tool industry, in the writer's twenty-two years of observation, is now making greater headway than at any previous period in the application of better bearings, and a safe prediction would be that the next important step in the way of improvement will be a more general adoption of ball bearings as standard equipment in the machine-tool industry.

# The Manufacture and Application of Extruded Copper Tubes

By GEORGE A. FOISY,[1] NEW HAVEN, CONN.

*The paper describes briefly the development of extrusion processes. Soft metals such as lead, tin, and lead-tin alloys have been extruded by heating them to a temperature just below the melting point and forcing them under pressure through dies. Collapsible tubes for holding dentifrice have been formed from cold metal in a press by a process in which a punch, entering a die, forces the metal to flow between it and the sides of the die, the tube being stripped off the punch by hand.*

*The paper next describes the cold extrusion of copper into tubes 7 mm. in diameter, having wall thicknesses of 0.0035 in. to 0.006 in. and 9 to 15 in. long. Electrolytic copper, 99.9 per cent pure, is extruded hot into bars about 1/2 in. in diameter. These are cut up into slugs about 7/16 in. long and subjected to two preliminary forming processes which reduce them to cups with wall thickness of about 1/10 in. and pressed bottoms of paper thinness. The cups are then extruded cold in a press by means of a die and punch, the material flowing out of the die around the punch through an annular space which is the exact cross-section of the finished tube. A pressure of 50,000 lb. is applied throughout 1/15 of a second, the energy thus expended causing the copper to assume a plastic state.*

*A final operation forms hexagonal ends to the extruded tubes which permits their assembly with closely fitting sides into cellular radiators for aircraft and automobile motors, condensers for refrigerants, unit heaters, and other heat-exchanging apparatus.*

THE extrusion process offers a method of manufacturing short lengths of thin-walled copper tubes which is more economical than the usual draw-bench method of manufacturing. The relative novelty of this method can be better appreciated if it is stated that the method is comparatively new from the manufacturer's standpoint and is used by not more than three or four companies throughout the entire world at this time, the reason for this being twofold: first, because the basic patents were held in America, and second, because the small amount of obtainable knowledge of this subject coupled with the limited demand for short lengths of thin-walled tubes acted as deterrents. There is no question but that, as more and more is learned of this subject and as new uses for the finished product appear from day to day, the industry offers a very fertile field for expansion.

## History

The extrusion process is not new inasmuch as we find that the first patents on record were taken out in England in 1797. However, up to within recent years, all patents having to do with this process covered the manufacture of lead, tin, or lead-tin alloys and finally led the way in more recent times to the copper-zinc alloys which contain small percentages of aluminum, lead, nickel, iron, or other ingredients. The first extrusion machines were comparatively clumsy tools somewhat resembling hollow cylinders containing a hole in one end and fitted with a piston. A lead ingot heated just below its melting point was then placed within the cylinder and pressure applied to it by the piston which was actuated by a screw. Continuous pressure on the ingot forced the lead to emerge from the hole in the bottom in the shape of a rod.

Later on, somebody thought of partially closing the orifice at the bottom of the cylinder by means of a rod somewhat smaller than the hole and held in a fixed position. When pressure was applied to the lead ingot as before, the lead emerged in the form of a hollow tube.

In 1863 a patent was issued in this country covering the manufacture of tin-lined lead pipe by the extrusion process. Up to that time, this pipe had been made by melting tin inside of the pipe but this was unsatisfactory because the tin did not always cover the entire inner surface of the pipe, lumps were often formed, and the coating was of very unequal thickness. The means employed to manufacture tin-lined pipe consisted in fitting a hollow ingot of tin into another of lead and then fitting the assembly into a cylinder somewhat similar to that previously described. As pressure was applied to the top of the piston, both the lead and tin ingots were extruded at equal rates, causing the finished pipe to have a smooth appearance both internally and externally, and also giving the interior a uniform, homogeneous coating of tin.

In 1873 a patent was issued for the manufacture of curved lead pipe such as is used for water traps. This method was simplicity itself. In the middle of the pressure cylinder such as has been previously described, an annular diaphragm or washer was placed with an opening larger than the fixed rod previously described and which determined the inside diameter of the pipe. By moving this diaphragm a trifle to one side or the other, it was possible to vary the volume of metal flowing through the opening on various sides and this, in turn, caused the pipe being extruded to be bent to one side or the other at will, depending on the direction in which this diaphragm was moved.

At about this time, there was established in New London, Conn., the business of making collapsible tubes used to contain a dentifrice. These tubes were made of pure tin and the method of extruding differed from that previously described in that the moving punch was set down into a die with a solid bottom containing the tin matrix. Upon the application of pressure, the metal in the die had no place to go except through the annular opening between the inner diameter of the die and the external diameter of the punch and consequently shot up the punch, from which it was stripped by hand. This method of extrusion, while different from that employed in the manufacture of copper tubing, constitutes the first method on record wherein a metal was extruded without the application of external heat.

Up to 1903, all the known methods of extrusion dealt with metals of a naturally plastic nature such as tin or lead, and all of them, with the exception just mentioned, had to rely upon the application of heat in order to make the extrusion practicable. In that year, 1903, a diemaker from Binghamton, N. Y., was experimenting with tools used in the manufacture of the two-piece "Bachelor Button" which he was then making and with which everyone is familiar. During his experimentations, he happened to make a punch a trifle long and rather than scrap it, he decided to put it to some use in order to ascertain its effect on the stock he was then using.

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Presented at the First National Meeting of the A.S.M.E. Machine Shop Practice Division and the New Haven Machine Tool Exhibition, New Haven, Conn., Sept. 6 to 9, 1927.

To his surprise, the finished button measured not $^1/_8$ inch long as he had expected, but approximately one inch in length, and had the form of a slender tube not in the least resembling the button he had started to make. After repeating the experiment a few times and obtaining the same result, he came to the conclusion that the metal, being confined on all sides except at the annular opening between the punch and die, was forced to flow through this opening when sufficient pressure was exerted by the punch. This, then, represents the first known case of the true cold extrusion of any metal harder than lead or tin and so, through various evolutions and improvements, but with no change in the fundamental discovery made by this diemaker, we arrive at the method in use at the present time.

### Manufacture

The tubes made by the extrusion process which is about to be described are composed of copper of a purity of at least 99.90 per cent. The tubes have a wall thickness of 0.006 inch in ordinary practice, although it is possible to make them with a wall as thin as 0.0035 inch without great difficulty.

The extrusion process divides itself into two main parts: first, the formation of a suitable cup, either from rod or sheet copper, and second, the extrusion of this cup into a thin-walled tube. As now practiced, these cups are made from extruded electrolytic-copper rods approximately one-half inch in diameter and 12 ft. long. These rods are extruded by the well-known process of heating the ingot close to its melting point, thereby rendering it soft or plastic enough to flow through the dies, which differs from the cold-extrusion method being described.

The extruded rods are cut up into small cylinders, each one of which contains nearly the same weight of metal as will be contained in the finished tube. The most economical way of cutting up these long rods consists in shearing off five lengths or cylinders at one time, each one of these lengths being $^7/_{16}$ inch long and weighing 140 grains or $^1/_{50}$ lb. This method of cutting or shearing makes high production practical since the presses doing this work have a speed of 125 strokes per minute and five pieces are cut off at each stroke.

These sheared pieces are subjected to two operations, the purpose of which will become clear if it is borne in mind that it is desired to make hollow cylinders out of these pieces preparatory to their being extruded.

The first of these two operations consists in the indentation of the small cylinder or slug and forms the start of the hollow cylinder which is the ultimate goal. After annealing, the indented slug is then subjected to a second forming operation which completes the work started by the first, and the erstwhile solid slug emerges as a small hollow cylinder with a bottom not much thicker than a piece of paper and actually perforated in the center. Both of these operations are performed on heavy draw presses with friction dials. These presses have a stroke of $3^1/_2$ inches and contain under-punches in order to push the work back up over the dies and out of the machines.

It may be wondered why two operations are necessary to form a hollow cylinder out of a slug of copper one-half inch in diameter and of the same height. This is due to the self-hardening properties of copper as it is being worked, inasmuch as the stresses set up in the displacement of so much metal become higher than the tensile strength of the steel in the punch after a comparatively short distance has been traversed by it, and it consequently becomes necessary to start the perforation, anneal the work and go through the second operation of making the slug hollow down to the bottom.

In describing the foregoing operations leading up to the actual extrusion of copper tubes, it must be remembered that the same hollow cylinder might have been obtained by forming a cup from sheet copper but the mechanical difficulties presented in such an abrupt folding, coupled with the extra operations necessary to make a base thin enough, make it much more economical to manufacture it as described.

### The Extrusion Process

After another annealing operation, this hollow cup is now ready to be extruded. At the present time it is approximately $^9/_{16}$ inch high, $^7/_{16}$ inch diameter and has a wall thickness of $^1/_{10}$ inch, and in one operation this cup will emerge as a tube 10 inches long and having a wall thickness of 0.006 inch, a reduction of 94 per cent. This offers a clear contrast between the extrusion method and that of ordinary drawing where a reduction of 50 per cent represents the usual limit.

The extrusion operation itself is done on a straight pillar drawing press having a stroke of but 2 in. This will no doubt seem all the more remarkable when it is considered that at each revolution of the machine a tube anywhere from 9 to 15 in. long is made. Fig. 1. shows the rear of the extrusion press.

The extrusion press is equipped with two sets of punches and dies but the punch holders are mounted on slides having a reciprocating longitudinal movement and operate at one-half the speed of the press, so that while there are two sets of tools, as just mentioned, but one tube is made per revolution of the machine.

The actual extrusion of the tube is somewhat as follows: The slug previously described, and which resembles a hollow cylinder, is picked up from a friction dial plate and set down within a die having an orifice in the bottom of exactly the same diameter as it is desired to obtain on the outside of the finished tube. Meanwhile, the punch which picks up this cup and places it in position within the die has a diameter equal to the desired internal diameter of the finished tube, so that a cross-section through the punch and die when in position shows a perfect annular opening which is the exact cross-section of the tube to be extruded.

On the punch, as well as the die, there is a shoulder whose purpose it is to fit tightly into the top of the die and not only to press down on the cup within the die but also to prevent the escape of metal, rendered plastic by the very high compression, up over the die instead of down through the annular opening at the bottom where it is supposed to go.

Having placed the cup in position inside of the die and with the punch directly over it and descending, the sequence of operations is as follows: First of all, the cup becomes subjected to a high pressure by the action of the press transmitted through the punch. This pressure has the effect of causing the sides of the cup to enlarge and to hug the sides of the die tightly; in fact, so much so that the work necessary to cause the outer molecules of this enlarged cup to slide in the die during the process of extrusion represents a considerable factor of the total work necessary to extrude the metal. This effect has been called surface friction, and the writer believes that this surface friction is responsible for the fact that certain metals having more plasticity than copper are harder to extrude.

Visualizing now the cup up to the point where it has bulged and has been set firmly on the shoulder in the die, continued application of pressure by the downward movement of the punch will cause either a rupture of the tools or will force the metal in the cup, now in a plastic state, through the annular opening between the punch and the die, thereby forming the tube. The reason for the plastic state of the copper is that the energy of impact, or the kinetic energy of the press, has been converted into heat at the point of impact, i.e., at the cup itself. Experiments made on an Olsen testing machine show that for a copper cup weighing 140 grains, a pressure of

approximately 25 tons, or 50,000 lb., is necessary to start the actual extrusion of the cup, but immediately the metal has started to flow, this pressure drops down to 10,000 lb., proving conclusively that the difference in pressures has gone into the creation of heat necessary to render the cup plastic before it can start to extrude.

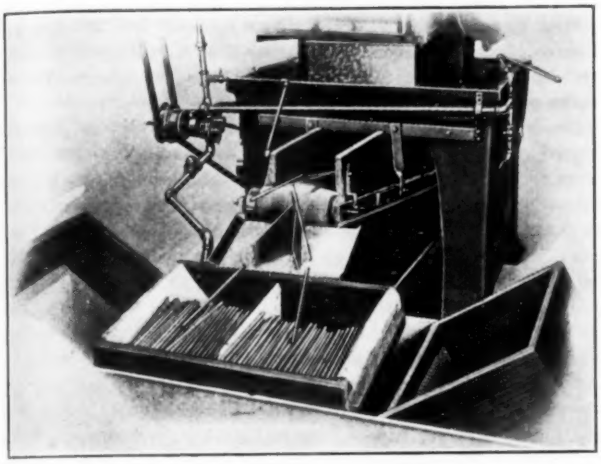

Fig. 1 Rear View of Extrusion Press, Showing Carrier Belt and Method Whereby Tubes Are Carried into Boxes

Now it will be remembered that a cup, which has been heated by the application of the energy in the press, is surrounded by steel tools which are good conductors of heat, and it may be wondered why these tools themselves do not dissipate the heat away from the cup and thereby prevent its becoming plastic. The reason for this is that the press has a speed of 125 r.p.m. and that at this speed, the work of compression and extrusion is done in one fifteenth of a second, from which it will be seen that the heat embodied in the cup does not have time to be transmitted to the tools before it is extruded. An interesting proof of this was found during the process of studying the various pressures required to extrude on an hydraulic press. Here the rate of extrusion is approximately seventy times less than on the standard extrusion presses and it was found that the heat caused by the work in the cup was transmitted through the outlying tools so rapidly that extrusion was impossible, and that fracture of the tools invariably occurred.

## Cooling and Lubrication

It is obvious from the tremendous amount of work done in extruding a tube, that a continuous succession of these operations would cause the tools used in the operation to become heated to such an extent that annealing would ensue, were a coolant not used. As explained before, an amount of heat capable of preheating the cup and thereby increasing its plasticity, would materially reduce the amount of work to be done in the actual extrusion operation and would also increase the life of the tools, but the difficulty in obtaining a satisfactory balance between an excess and a paucity of heat is still a problem which will only be solved by future research. Not only must the coolant remove heat from the tools but it must also quench almost instantaneously the extruded tube issuing from the die at a high temperature, lest annealing and spoilage of the tube result.

In addition to these two duties imposed upon the coolant, it must possess two other qualities, namely, lubrication, and relatively high viscosity at elevated temperatures. Lubrication is needed to facilitate the sliding of the cup in the compression stage immediately before extruding in order to diminish the surface friction between the outer wall of the cup and the inner surface of the die.

The only substance which has satisfactorily performed all of the above four functions is lard oil. Not only is it an excellent coolant, but its high flash point and viscosity enable it to be used where almost all other commercial types of oils have been found useless. At various times aqueous soap solutions have been tried, with and without lard oil, but the results have been disappointing. As a matter of fact, the extra friction entailed by the use of experimental lubricants, other than lard oil, was so pronounced that a decided grind or crunch could be heard every time a tube was being extruded, demonstrating an audible proof of the extra friction encountered.

## The Tool Problem

There remains one subject pertaining to the extrusion process which is the cause of considerable variation in production costs and that is the tool problem. If one considers that a pressure of 50,000 lb. is needed to start the extrusion of the tube and that this, reduced to unit pressure, becomes 200,000 to 250,000 lb. per sq. in. on the punch, it will be appreciated that it is rather a delicate problem to find steels capable of standing up under stresses almost as high as their yield points. Moreover, the proper heat treatment and design of these tools require the utmost care, since the least variation or departure from tried and tested standards means that the tools either will not function properly or else that their lives will be very short.

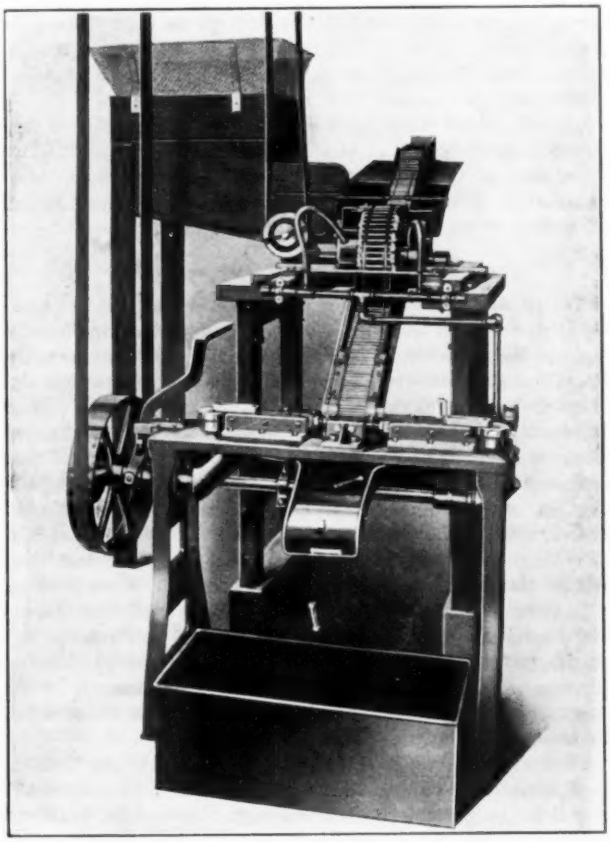

Fig. 2 Combination Annealing and Expanding Machine

(In this machine, the ends of the tubes are annealed and then expanded into a hexagonal form. At the same time the tubes are dimpled or indented.)

The foregoing represents the fundamental principles involved

in the manufacture of thin-walled copper tubes. While this method is styled cold extrusion, it has been shown that there is no such thing as true cold extrusion since plasticity of the copper, and consequently its extrusion, cannot be obtained without heat. The difference between the method above described and that discovered 130 years ago is that in one case the energy of the press is transmitted into terms of heat at the work instead of supplying the requisite heat by external means.

### Application

Once extruded, these tubes are sawed to the desired length, are given a hexagonal shape on the ends as shown in Fig. 2, and are finally tested individually at 35 lb. air pressure before passing on to be assembled into the object for which they are specified.

Primarily, these tubes serve an ideal purpose in almost all types of heat exchangers. The most common types of heat exchangers are radiators, whether of the type used in automobiles or in domestic heating. In the first, the water traveling through the system absorbs heat from the cylinder jackets, which is in turn dissipated to the surrounding atmosphere when passing through the radiator. In the second case, steam condensed within the radiator delivers its latent heat to the radiator, from which it is in turn radiated and dissipated to the outer air.

Returning to the tubes, the wall is very thin (0.003 to 0.006 inch), consequently any difference in temperature between the two sides of the tube tends toward rapid equalization. In other words, the rate of heat conductivity through the walls of the tube is rapid on account of the fact that the rate of heat transmission is a function of the thickness and this, of course, is at a minimum in tubes of this thinness.

Secondly, these tubes are made of copper, and copper is surpassed only by silver in the conduction of heat. With this explanation of the fitness of thin-walled copper tubes as ideal transmitters of heat, we pass on to a few practical illustrations of different types of heat-exchanging apparatus.

### Radiators for Airplane and Automobile Engines

Shortly after the termination of the World War, the Engineering Department of the U. S. Air Service made a comprehensive study of the then existing types of radiators used to dissipate the excess heat of airplane engines. During the course of their study, which included radiators in use on European planes as well as American, it was ascertained that most of the European radiators were made up of a multiplicity of individual tubes and that these radiators seemed to be efficient, were remarkably free from troubles, and were readily repaired when accidents occurred. At that time, the British Government had established a standard tube diameter of ten millimeters and the French Government had set the standard at seven millimeters. The tubes used by both these Governments were made of brass and were drawn. The English, however, were using a tube 6 in. long or approximately 15 calibers (the ratio of the length to the internal diameter). The French used a tube approximately 5 in. long or 12 calibers, which represented the practical manufacturing limit in the drawing of such a slender tube.

Further investigations and tests by the United States Government brought out the fact that if tubes from 30 to 35 calibers and 8 to 9 in. long could be obtained, higher efficiencies would be reached. It was then determined that the most practical method of manufacturing tubes of this description was the extrusion process and it is significant that from that day to this, these tubes have been standard with the United States Government on their water-cooled planes. The tubes most commonly used have a wall thickness of 0.006 in., are close to 7 millimeters in diameter, and ordinarily have a finished length of 9 in. Each tube weighs 107 grains or $^1/_4$ of an ounce. Each end of the tube is expanded into a hexagonal outline so that many are packed together, the ends of each tube nest perfectly against their neighbors, and when the packed assembly is dipped in solder to seal the hexagonal faces the result is that each tube is firmly attached on six sides, giving the maximum of strength and yet presenting as large an amount as possible of open space or free area for the passage of air. With very few exceptions, all of the tubes used for airplane radiators have a smooth body, as the use of air baffles or other obstructions is detrimental.

Besides the tubes with a plain or smooth body, as just described, there are also made other types which have a series of dents or air baffles on their bodies and which project into the air stream. These baffles serve the purpose of deflecting the air in its passage through the tube, imparting to the air a highly turbulent effect and causing it to scour the inside walls, thereby breaking up the air film normally adhering to the walls of the tube and tending to impair the transmission of heat from the tube to the air. This scouring effect is necessary and desirable when dealing with air speeds commonly encountered in automobile practice, but when the air velocities begin to mount over 7000 f.p.m., the very energy of this air is sufficient to break up the air film just mentioned and any baffling of the tube increases the head resistance of the radiator and decreases the speed of the plane without proportionately increasing the heat dissipating capacity of the radiator.

### Condensers

These tubes in shorter lengths are also coming into prominent use as condensers for automatic refrigerators using any of the hydrocarbons or $SO_2$ as a refrigerant. As is well known, the cycle of all compression types of refrigerating machines is the compression of the gas, condensation, and final expansion. After the gas has been compressed it is obvious that there must be removed from it, in order to effect condensation, the same amount of heat which it absorbed during the expansion cycle. It is for the purpose of removing this heat that condensers are made using these tubes as a matrix.

### Blast Heaters

Extruded tubes are coming into very prominent use in the manufacture of blast heaters or radiators. This type of radiator is to be distinguished from the well-known household type in that the stream of air is forcibly directed through the air spaces of the tubes, is thereby heated by the latent heat of the steam condensed within the tubes, and by the very movement of the air itself is diffused into the room in which it is placed. This type of radiator has effects entirely different from the ordinary direct radiator with which everyone is familiar and which heats the surrounding air by convection and radiation only.

The blast system of heating has many advantages, chief among which are the very short warming-up periods due to the almost instantaneous diffusion of heat, and the high efficiencies in heat transmission obtained with them. The writer recalls having seen an installation of such heaters mounted in a building 52 feet above the floor level in a monitor roof and yet the ground level was entirely comfortable, was free from drafts, and the temperature in all parts of the room was very uniform. Such movements of air over long distances can only be possible by heaters offering the minimum amount of resistance to air flow, and this resistance is kept at the minimum point by the construction and assembly of the tubes themselves. This type of blast heater is now in general use for heating industrial buildings, school rooms, offices, garages, or in fact in any place where an appreciable amount of heated air is to be delivered, and the writer believes that in the near future it will be possible to heat our homes by some similar type of radiation.

# Ball-Bearing Machine-Tool Spindles

By THOMAS BARISH,[1] JAMESTOWN, N. Y.

*This paper is a review of the three types of ball-bearing machine-tool spindles now in use, showing how rigidity is obtained in each type and what results are secured. There is also a historical review of the first type, which was originally put into service over ten years ago and has since received minor improvements. The three main groups are:*

(*a*) *Two-bearing, manually adjusted spindles*

(*b*) *Automatically spring-adjusted spindles*

(*c*) *Three-bearing spindles, adjustable and non-adjustable.*

*Comparisons are made between the various types for their rigidity, and some deflection curves and actual measurements of rigidity are quoted.*

## I—TWO-BEARING, MANUALLY ADJUSTED SPINDLES

THE first notably successful ball-bearing heavy-duty machine-tool spindles were built in 1917. These machines were all of the two-bearing, manually adjusted type using one angular-contact or radio-thrust bearing at each end, the two bearings being adjusted with initial thrust applied by a nut on the shaft in back of the smaller bearing. Fig. 1 is a typical example showing the Hart-Parr shell lathes built in 1917 for turning 16-in. shells.

### Initial Load and Deflection

These first machines showed that the ball bearings could be more rigid than plain bearings, but to do so they must be pulled very tight: the ball bearings must have a relatively large initial load. After a few experiments, the initial load was set at approximately 10,000 lb. thrust, about as much as the bearings would stand without impairing their life.

The initial load was not accurately measured because a wide variation was permissible—anything from 8,000 to 12,000 lb. proved satisfactory. The load was controlled by the simple method of pulling the adjusting nut as tight as possible with a six- or eight-foot pipe length on the end of the wrench.

Fig. 2 shows the axial-deflection curves for the bearings used in these first machines. These bearings of ten years ago show larger deflections than the more recent bearings with closer race curvatures (Fig. 4).

Both the large bearing at the front and the small bearing at the rear were of the radio-thrust or angular-contact type. In the first machine both bearings were RT 100 per cent types. In the later designs the smaller bearing at the rear is an RT 200 per cent type with greater contact angle and correspondingly greater thrust capacity, while the large bearing next to the work remains an RT 100 per cent type with a smaller contact angle to give greater rigidity in a radial direction.

The rigidity obtained by the large initial load can be determined from the deflection curves of Fig. 2. Consider first the effect of large thrust loads from an end-facing or boring operation.

TABLE 1 AXIAL DEFLECTION UNDER THRUST LOAD IN BALL-BEARING SPINDLE OF FIG. 1

| | | | |
|---|---|---|---|
| Thrust load from work assumed, lb. | 1,000 | 5,000 | 10,000 |
| Load on large bearing increases from 10,000 to | 10,500 | 12,500 | 15,500 |
| Load on small bearing decreases from 10,000 to | 9,500 | 7,500 | 5,500 |
| Difference equals load from work | 1,000 | 5,000 | 10,000 |
| Corresponding axial deflection (from curve) in. | 0.0002 | 0.00085 | 0.00178 |

[1] Assistant Chief Engineer, Gurney Division, Marlin-Rockwell Corporation.

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### Design

These first machines showed that the spindle itself had to be stiffer when mounted on ball bearings, largely because the ball bearing approaches a point support, whereas the plain bearing offers support over a longer length of spindle. This calls for increased spindle diameters except where the original spindle is oversize.

On the other hand, the relatively narrow ball bearing can bring the main point of support much closer to the nose of the spindle and reduce the overhang of the work, a very important factor for heavy roughing cuts, for greater accuracy, and for large overhangs.

Furthermore, the narrow bearings permit a definite shortening of the spindle and the frame. The resultant saving in cost of frame and the elimination of hardening for shafts and scraping for bronzes or babbitts materially reduces the cost of the machine.

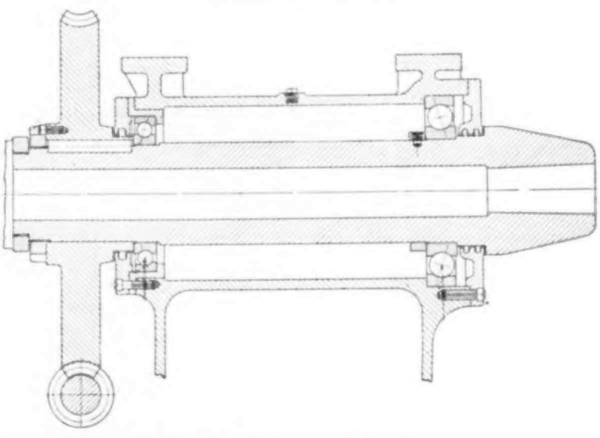

Fig. 1 Ball-Bearing Spindle of 16-In. Shell Lathe Built in 1917

(Typical example of first type of heavy-duty machine-tool spindle using two opposed angular-contact bearings.)

One manufacturer who regularly made both bronze-bearing and ball-bearing machines of a certain type reports a $400 lower cost of production for the ball-bearing machine.

This first type of ball-bearing spindle, the two-bearing opposed mounting, requires a rigid headstock, especially endwise. Otherwise the large initial loads pull the two end walls together. The very first experimental machines showed well over 0.010 in. movement under the initial load. The addition of several ribs and a thickening of the walls reduced this to much less than 0.005 in.

The ball bearings on the spindles of these first machines show a small saving in power. However, the power saving is of minor importance compared to the large increase in production that can be obtained. This is most noticeable under higher-speed roughing cuts. One authority explains the difference as folllows: A bronze-bushed lathe might not permit more than 0.015 in. feed because the flexible oil film will permit the cut to vary from 0.012 in. to 0.018 in., with resultant danger of chatter. A ball-bearing lathe with the same tools and cuts can use the full 0.018-in. feed and perhaps even 0.020 in. because of the greater steadiness. A specific comparison obtained on a machine of this type is given at the end of Part II of this paper.

The ball-bearing spindle is also useful for wide form-tool work,

For example, a ball-bearing spindle is cutting all the cooling ribs on the Wright Whirlwind airplane-motor cylinder. All the sixteen ribs on the steel forgings are cut in one operation with a multiple tool arrangement.

The increased steadiness also prolongs tool life and proves valuable for complicated and expensive tools and for difficult set-ups.

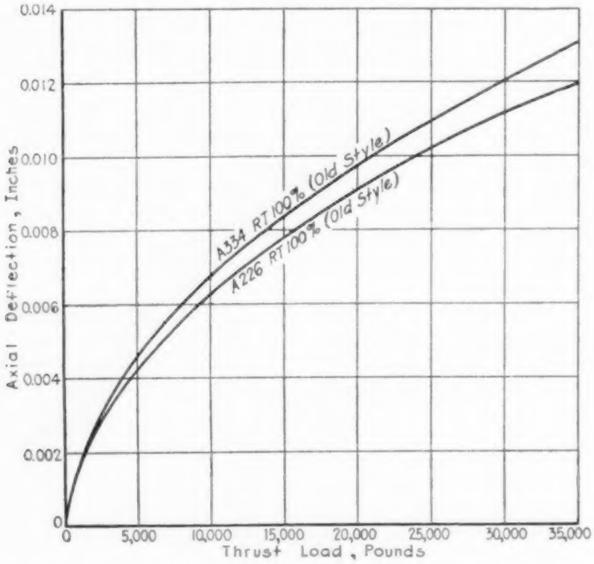


FIG. 2 AXIAL-DEFLECTION CURVES FOR LATHE SPINDLE SHOWN IN FIG. 1, DESIGN AND BEARINGS OF 1917

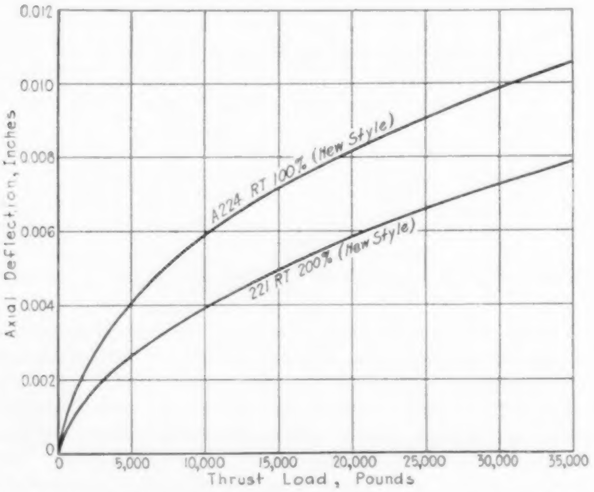


FIG. 3 AXIAL-DEFLECTION CURVES FOR MORE RECENT TWO-BEARING SPINDLE

[Similar to Fig. 1 but smaller (4 in. instead of 6 in.).]

The second important advantage of ball bearings was not realized until after the bearings were in use for some time. They require little attention for maintenance. There is a tendency for the bearings to "wear in," or perhaps it would be better to say "roll in," during the first 50 to 100 hours' operation. Then if kept clean they need no further attention for from two to six years, depending upon the severity of the service and the suitability of the mounting for the work.

The need for a readjustment after the "rolling-in" period can be avoided in all slow-speed and medium-speed spindles by setting the spindles up slightly tighter at the start.

## RECENT TWO-BEARING SPINDLES

The latest developments in two-bearing opposed mountings are arranged to meet the demand for heavier cuts and greater production by the use of even stiffer frames and spindles and certain modifications in the ball bearings for increasing the rigidity.

Fig. 3 shows the axial-deflection curves for bearings used within the last 3 or 4 years. These are smaller bearings than those of Fig. 1, but probably handle even heavier work. Note the much flatter deflection curve. These bearings use an initial load of about 4000 lb. The deflections are compared in Table 2, which is similar to Table 1.

TABLE 2 AXIAL DEFLECTIONS UNDER THRUST LOAD IN RECENT TWO-BEARING OPPOSED MOUNTINGS (RECENT CLOSE-CURVATURE BEARINGS)

| | | | |
|---|---|---|---|
| Thrust load from work assumed, lb. | 1000 | 4000 | 8000 |
| Load on large bearing increased from 4000 to | 4550 | 5750 | 8000 |
| Load on small bearing decreased from 4000 to | 3550 | 1750 | 0 |
| Difference equals load from work | 1000 | 4000 | 8000 |
| Corresponding axial deflection, in. | 0.00018 | 0.0008 | 0.0017 |

The effect of a radial load or a combined radial and thrust load is far more difficult to determine. The front bearing, because of its large initial thrust, will act under pure radial load somewhat like a radial bearing that is tightly fitted. To give some idea of the radial deflection, Fig. 4 (upper curve) shows the deflections for this same bearing if it were a radial bearing made with a line-to-line internal fit. Note how flat the curve becomes under heavy loads. The initial load moves the operating conditions up into the flat part of the curve. In other words, that part of the curve marked *AB* is moved down to the origin to the points marked *ab*.

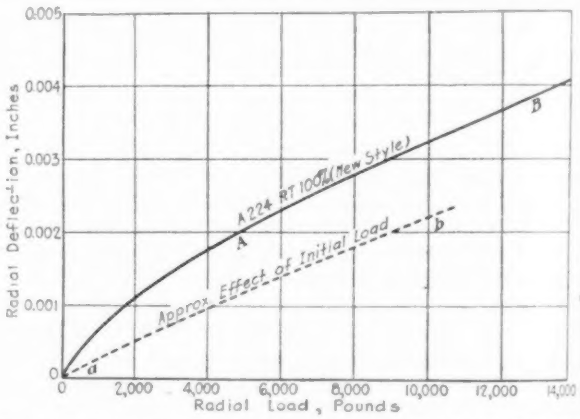


FIG. 4 RADIAL DEFLECTION (APPROXIMATE) FOR FRONT BEARINGS OF TWO-BEARING OPPOSED SPINDLE

(Same bearing as shown in Fig. 3. Note effect of large initial load in flattening curve.)

These small deflections compare favorably with those of the usual bronze bearings for a lathe of this size with their 0.002-in. to 0.005-in. initial looseness and their relatively flexible oil film.

In selecting the initial load of 4000 lb., the rigidity of the spindle was roughly checked under this selected load and again under an initial load about twice as large. In each case the spindle deflection was measured when adding a large radial load and then a large thrust load imposed by wedging a beam against the spindle nose. With 4000 lb. initial load the axial deflection was about 0.0008 in. and the radial deflection about 0.0009 in. Doubling the initial thrust load decreased these deflections to 0.0005 in. and 0.0006 in. This gives a clear conception of the extreme rigidity of these modern spindles.

The simple two-bearing opposed mounting adapts itself readily to large hollow spindles that are relatively short, for shaft diameters of 6 in. to 12 in. A number of such machines have been working successfully for several years peeling billets in

steel mills, a rather severe service because of the heavy cuts and the tough, uneven skin cuts.

## II—SPRING-ADJUSTED SPINDLES

Spring-adjusted ball-bearing spindle mountings have been used mostly for medium-speed and high-speed precision grinders. The bearing capacity is less at the higher speed and calls for more careful control of the initial load which can be obtained by springs. Also these spindles require finer or more frequent adjustments. The springs can be arranged exactly to control the initial load and to avoid entirely the need for readjustment.

Fig. 5 shows the type of spring-adjusted grinding spindle that has been in service in the Gurney ball-bearing plant for about 15 years for grinding ball-bearing race surfaces. The spring adjustment is fully automatic. That is its main advantage. There is no need for any readjustment during the life of the bearings.

The initial load in this machine was set at about 100 lb.; both bearings are of the RT 100 per cent type. The smaller contact angle means less radial clearance or looseness in the original bearing, and hence greater radial rigidity.

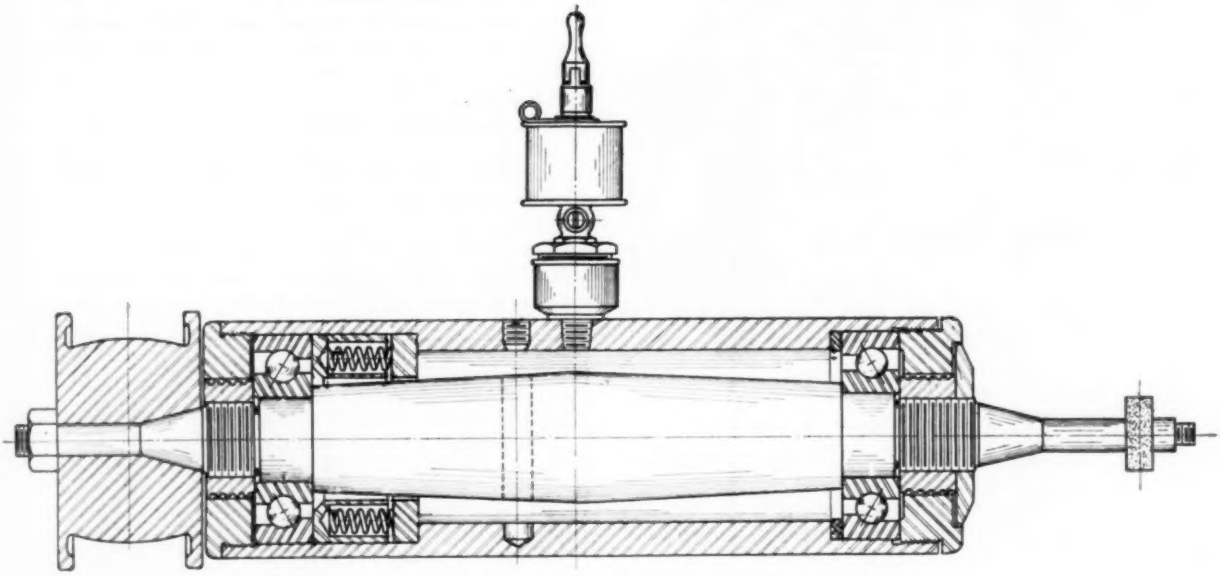

Fig. 5 Spring-Adjusted Spindle, Small High-Speed Grinder

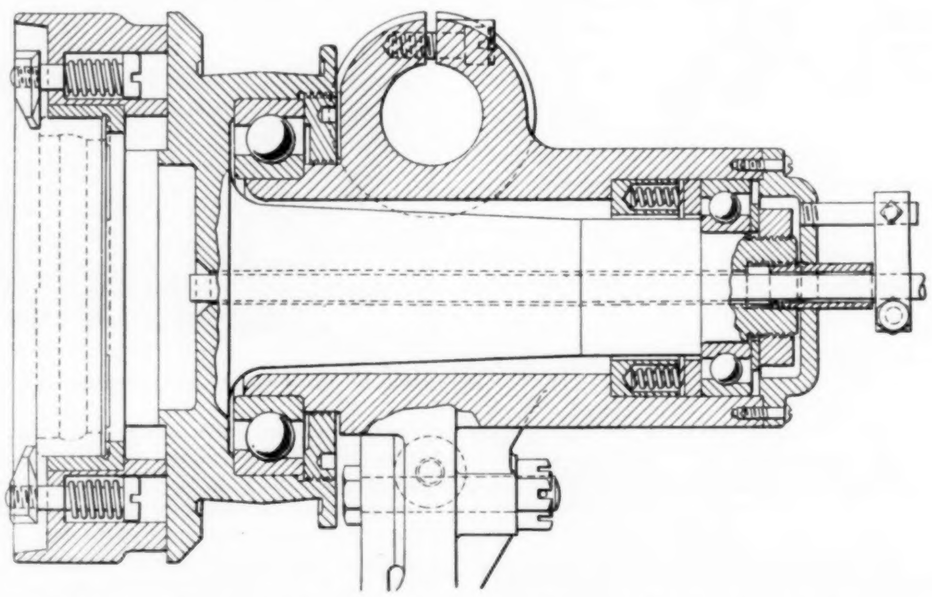

Fig. 6 Chuck Spindle or Work Head of Grinder Shown in Fig. 5. Spring Adjusted

We stop here to point out a limitation of the spring-adjusted ball-bearing spindle. A rapidly reversing thrust will cause the springs to deflect in one direction, very slightly, of course, but enough to affect quality of finish and accuracy in fine work. A similar effect occurs under large radial shock loads. The two angular-contact bearings tend to drop down into the bottom of the groove, and any slight yield of the spring permits this movement.

The automatically spring-adjusted spindle has proved itself desirable for certain types of work, viz.:

*a* For small high-speed grinders where the loads are rela-

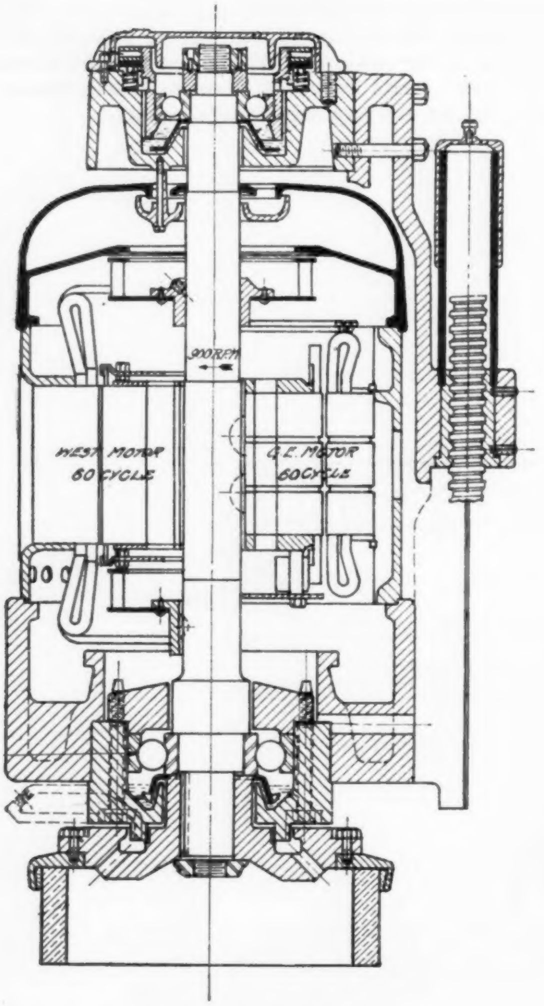


Fig. 7 Vertical Surface Grinder

(Spring-adjusted main-spindle angular-contact bearing at top loaded by spring to support weight of spindle and provide initial load.)

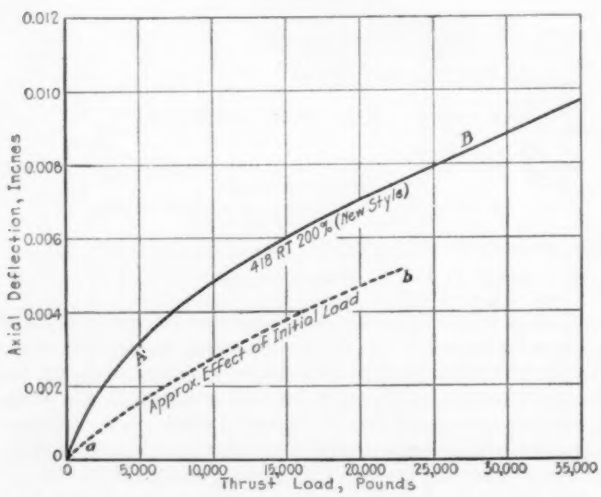


Fig. 9 Axial Deflection for Large Bearing at Lower End of Spindle Shown in Figs. 7 and 8

(Note effect of large initial load in flattening deflection curve.)

tively light and the spring load can be made large compared with the loads;

*b* For thrust loads of any size that are always in one direction. These may be combined with radial loads that are not large compared with the thrust load;

*c* For very steady loads (rare).

Fig. 5 is an example of the first class where the speeds are high and the loads relatively light. However, this design is not quite rigid enough under heavy grinding cuts, where the spindle or work is rapidly oscillated.

Fig. 6 shows another example where the loads are both radial and thrust, but relatively light. This is the work spindle or chuck spindle of the same ball-bearing grinding machines. Here the initial loads were set higher, the speed being lower and the load from the work mostly radial. Note how the springs are distributed and guided to apply the load uniformly

Figs. 7 and 8 show a well-known and highly successful application of a spring-adjusted spindle for heavy precision grinding

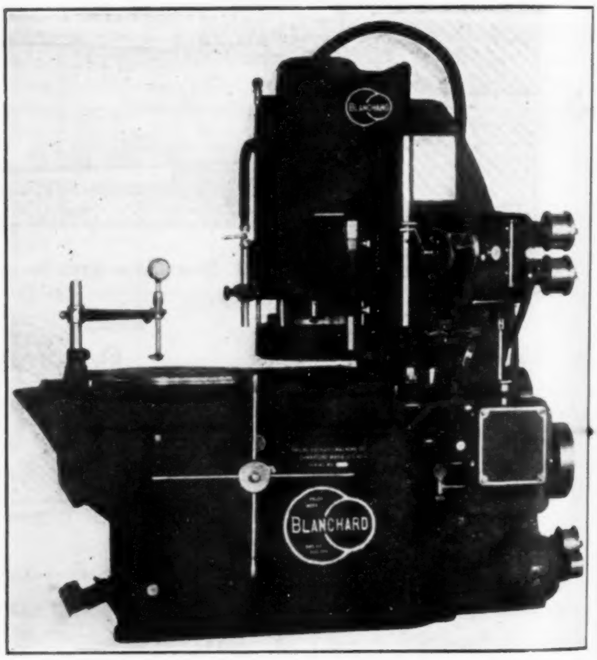


Fig. 8 Vertical Grinder Using Spindle Shown in Fig. 7

where the loads are almost all thrust or axial. This is a vertical surface grinder. The springs under the top bearing are set to carry all of the weight of the rotating parts and supply an additional large load for holding the bottom bearing tight.

Fig. 9 gives the deflection curve for the bottom bearing. The deflection of the top bearing does not matter because the springs follow up the upward spindle movement. Table 3 shows the effect of additional load from the work.

TABLE 3 SPINDLE DEFLECTION UNDER LARGE THRUST LOADS—SPRING-ADJUSTED SPINDLE

| | | | |
|---|---|---|---|
| Thrust from work, lb. | 500 | 1000 | 2000 |
| Bearing load increases from 1500 to | 2000 | 2500 | 3500 |
| Bearing deflection, in. | 0.00007 | 0.0003 | 0.0006 |

Note how this action differs from that of Tables 1 and 2. The load on the large bearing next to the work increases by the full amount of the added work load, whereas in Tables 1 and 2 part of the work load is carried by reducing the load on the smaller bearing at the other end of the spindle. Note the liberal bearing sizes to take care of this condition.

Figs. 10 and 11 show another very successful mounting for heavy loads that are mostly thrust but for an entirely different class of work. This machine is a special form of automatic used for turning nut blanks. The load from the work is practically all thrust, and is carried by the large angular-contact bearing up close to the work. The springs are carried inside of the nut next to the inner race of the small bearing. If this nut were pulled up tight the mounting would resemble a positively adjusted spindle.

This machine offers an opportunity to compare production results because the product, nut blanks, is standardized in size and material. The regular production obtained on the machine shown in Figs. 10 and 11 is 100 two-inch nut blanks per hour as compared with 23 per hour, the best possible for any existing plain-bearing machine of this type. Tool life is at least 10 per cent greater. Of course, these results are partly due to the peculiar tool design and set-up, but the machine manufacturer attributes a large part of the increased production to the use of ball bearings on the spindle.

Another unusual feature of this machine is the very narrow cut-off tool made possible by the endwise rigidity of the ball-bearing spindle. They are as thin as 0.062 in. in the smaller machines. This feature materially reduces the percentage of waste material for cut-off on the narrow, large-diameter nut blanks. Two cut-off tools are used on opposite sides to balance the tool pressures, and the cut-off tools do not go completely through the work. This arrangement combined with the relative steadiness of the ball-bearing spindle permits very thin cut-off tools.

The spring-adjusted spindle requires very careful selection of the correct bearing type. The contact angle for both bearings must be chosen according to the type of load—whether the thrust is predominant or the radial. The spring load also requires attention. Note that the front bearing next to the work should have a light press fit on the shaft not less than 0.0003 in., and a very close fit in the housing, approximately a push fit. Any looseness at these two points would be objectionable on account of its possible effect on the work.

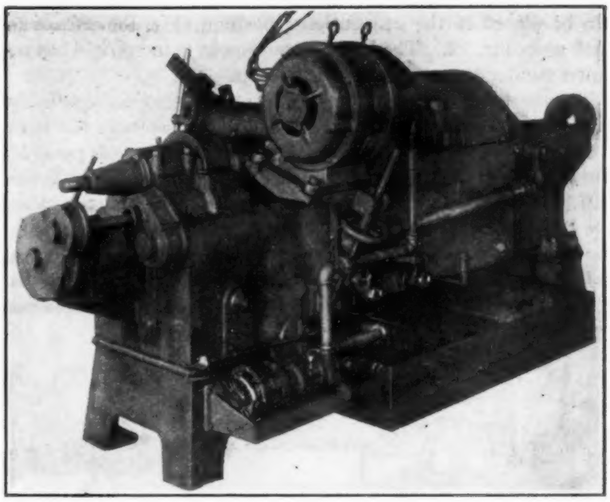

Fig. 11 Machine Using Spindle Shown in Fig. 10 Producing 100 Two-Inch Nut Blanks per Hour

## III—THREE-BEARING SPINDLES

Three-bearing machine-tool spindles (some have more than three) are all arranged to carry thrust load in both directions at the work end. One bearing carries the work thrust and a second bearing, also at the work end, carries the thrust in the opposite direction and applies the adjusting or tightening thrust.

Fig. 12 shows a non-adjustable three-bearing unit used mainly for small spindles and for mountings that do not require extremely careful setting of the initial load.

The two angular-contact or "radio"-thrust-type bearings at the nose come in pairs. They are ground by the bearing manufacturer so that the two outer rings can be clamped together and also the two inner rings, the result being a small initial load. The earliest form of these matched bearings is the Gurney Duplex, which has been widely used in other locations like worm drives to carry reversing shock-thrust loads. Note that these bearings

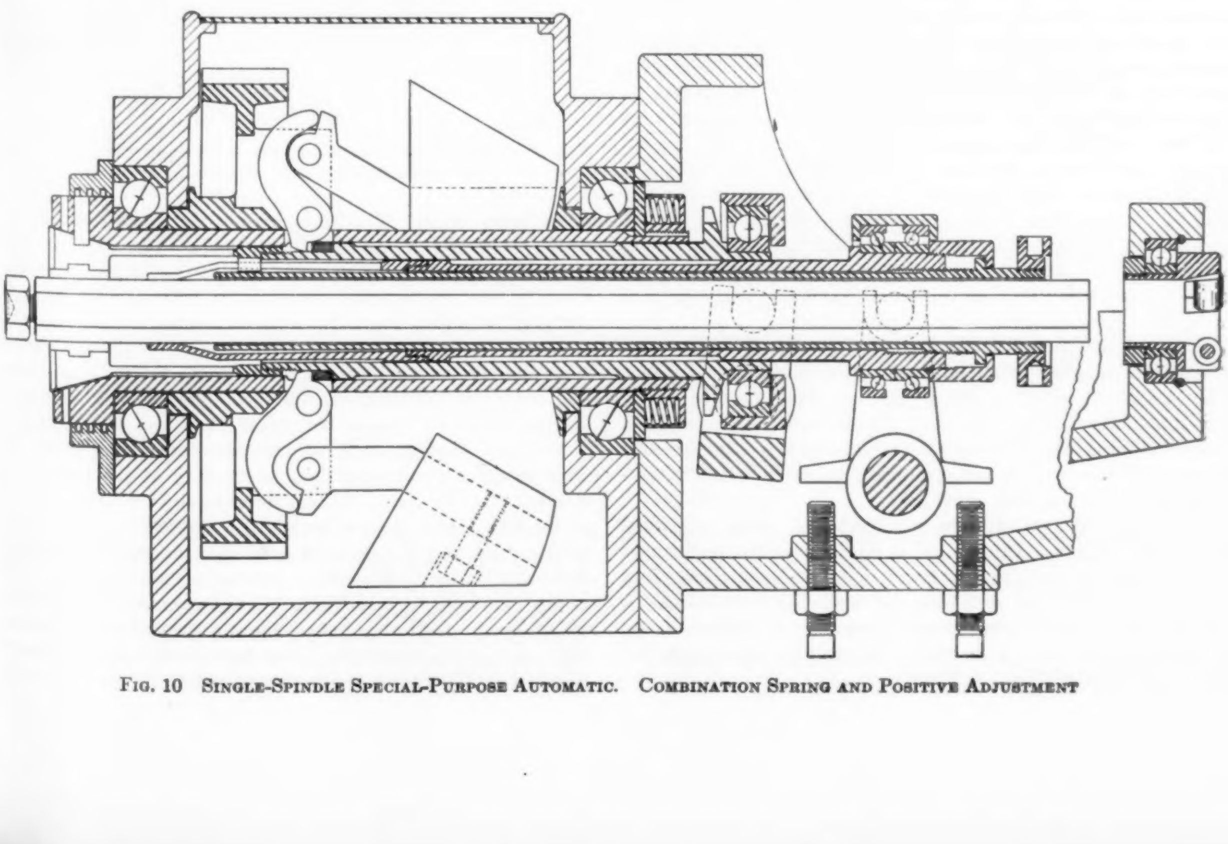

Fig. 10 Single-Spindle Special-Purpose Automatic. Combination Spring and Positive Adjustment

can be placed in the conventional position (Fig. 13) or back to back as in Fig. 12. The latter arrangement is more rigid but requires greater accuracy in aligning the spindle.

To produce extreme rigidity these Duplex-type bearings should have the maximum possible initial load. This calls for close cooperation between bearing manufacturer and user. If possible, the load should be varied somewhat for each individual application. Lower speeds call for larger initial loads. Furthermore, the initial load will be increased by even a light press fit on the shaft because the inner ring expands. Similarly slight errors in alignment or squareness will disturb the initial tightness. The duplex bearings are therefore commonly set a small amount

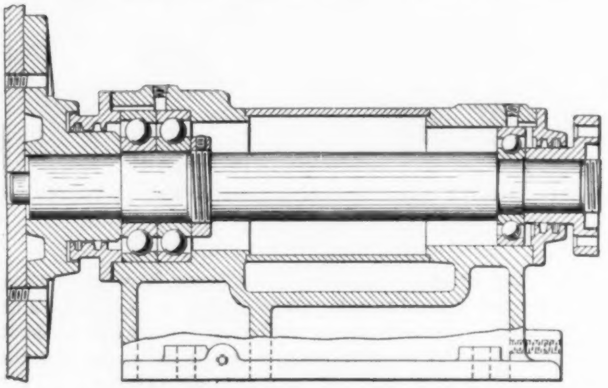

FIG. 12 SPINDLE OF LARGE HORIZONTAL DISK GRINDER USING OPPOSED PAIRED ANGULAR-CONTACT BEARINGS, NON-ADJUSTABLE

(The two bearings are back to back for rigidity.)

below the maximum possible tightness to avoid difficulty from these sources. The duplex type of mounting finds its greatest usefulness on spindles not requiring extreme rigidity—for example, the grinder spindle of Fig. 12.

### SEMI-ADJUSTABLE MOUNTINGS

This type of three-bearing mounting is also manufactured in semi-adjustable form, i.e., so that it can be adjusted when making the spindle, if necessary. They are not adjusted afterward, except perhaps when overhauling the machine. Fig. 14 shows a small high-speed vertical milling machine. The two halves of the Duplex bearing are separated by two sleeves, one between the inner rings and one between the outer rings. Both sleeves and all four bearing rings are clamped tight. The sleeve between the outer rings is split. To readjust, remove the nut holding the outer races and lower the spindle assembly about two inches until the split ring can be taken out. The split ring is then ground down in width from 0.001 in. to 0.002 in. and the unit reassembled. This arrangement is relatively simple and foolproof—yet quite rigid with all parts clamped.

A very similar mounting has been used extensively on the work spindle for bore grinders and on gear lapping and testing machines. The spacer between the outer races is omitted. The initial adjustment is made by positioning the end cover, which is bolted instead of threaded. To readjust the bearings it is only necessary to take off the end cover and machine off about 0.001 in. Sometimes laminated shims are provided.

The manufacturers of these machines test every individual spindle for rigidity. In one case a 400-lb. weight overhung 14 in. from the spindle nose must not produce radial deflections larger than 0.00025 in. at the spindle nose. In a second case a 750-lb. thrust must not produce more than 0.001 in. deflection, and a 750-lb. radial load 12 in. from the spindle nose must not give more than 0.00075 in. deflection.

### ADJUSTABLE THREE-BEARING SPINDLES

This same design of Fig. 14 can be made fully adjustable by omitting the spacer between the outer rings. The threaded end cover then becomes an adjusting nut. However, this arrangement is rarely used.

Fig. 15 shows a common three-bearing adjustable mounting as installed on a multiple-spindle automatic. The bearings are placed so the one nearest the nose takes the work thrust. The spacer between the outer rings is clamped solid. There is no spacer between the inner rings, and adjustment is provided by moving the inner ring of the inside bearing by means of the nut. This inner ring must be free to move on the shaft, but the front bearing, which takes most of the load, is tight on the shaft.

The initial load is easily controlled. For the machine shown in Fig. 16 it was set at 1200 to 1500 lb. (3-in. spindle). The pitch of the thread was selected so that a man pulling as hard as possible on an ordinary 8-in. to 10-in. wrench would exert the correct endwise force and produce the desired initial thrust.

Fig. 16 shows how this design is applied to large spindles, in this case a single-spindle automatic (about 6 in. shaft size at main bearing). Both inner races of the front bearings are clamped by a nut. The large bearing is fairly tight in the housing. The smaller bearing applies the tightening thrust through the sleeve around the outer race and the large nut.

The most important single feature in all of these ball-bearing machine-tool spindle mountings is the large initial load that produces the rigidity. The accuracy of the ball bearing permits

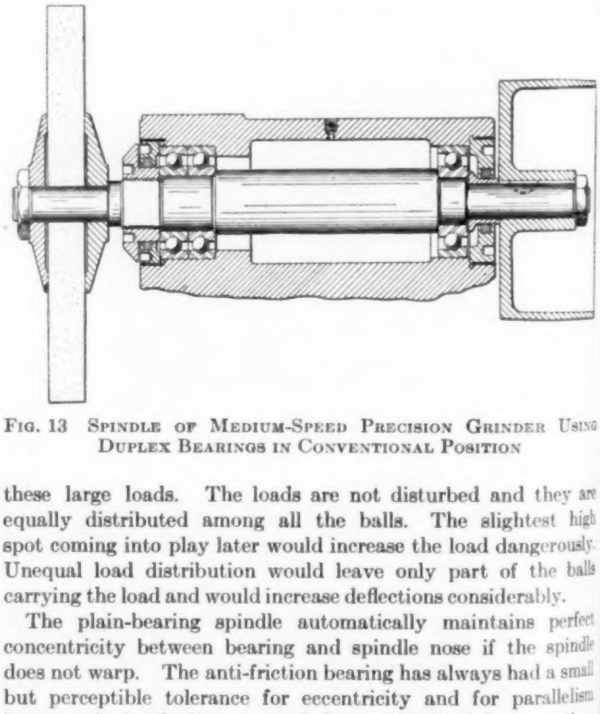

FIG. 13 SPINDLE OF MEDIUM-SPEED PRECISION GRINDER USING DUPLEX BEARINGS IN CONVENTIONAL POSITION

these large loads. The loads are not disturbed and they are equally distributed among all the balls. The slightest high spot coming into play later would increase the load dangerously. Unequal load distribution would leave only part of the balls carrying the load and would increase deflections considerably.

The plain-bearing spindle automatically maintains perfect concentricity between bearing and spindle nose if the spindle does not warp. The anti-friction bearing has always had a small but perceptible tolerance for eccentricity and for parallelism between the inside diameter and the race track of the inner ring. This produces a corresponding eccentricity at the nose of the spindle. In the past the small eccentricities were removed on the finer precision tools by taking a light finishing cut on the spindle nose after it was mounted in its own bearings. To meet this condition more efficiently, it has become necessary to develop a new grinding method for ball-bearing inner races that now yields almost absolutely true running surfaces for the bore and race track of the inner ring. The first lot of bearings made by this new method (3-in. bore) showed about 15 per cent of the

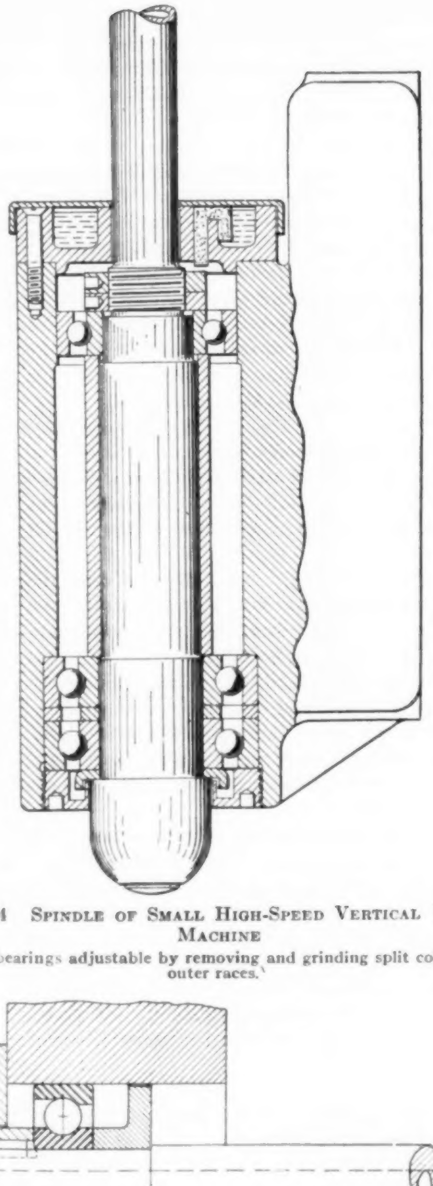

FIG. 14 SPINDLE OF SMALL HIGH-SPEED VERTICAL MILLING MACHINE
(Duplex bearings adjustable by removing and grinding split collar between outer races.)

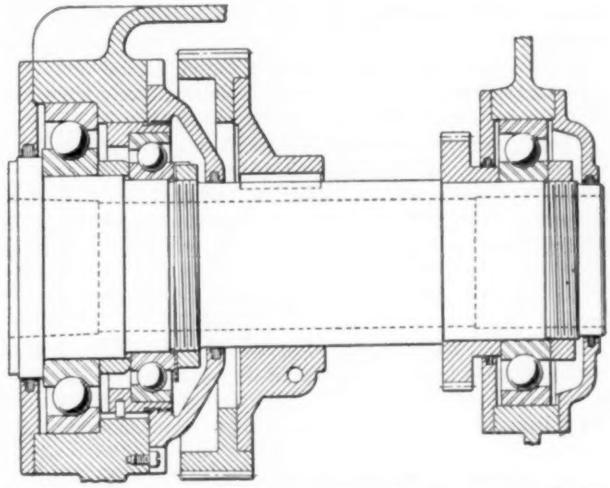

FIG. 16 THREE-BEARING FULLY ADJUSTABLE MOUNTING ON LARGE SLOW-SPEED AUTOMATIC SPINDLE

to take out radial play. These bearings can even be made so the balls are squeezed from 0.0001 in. to 0.0004 in. in assembling the bearing. The one bearing is more than ample for the great majority of designs because the bearing is so far from the work.

In a few rare cases where the overhang is large or where the spindle carries heavy load near both ends, it becomes necessary to mount two opposed bearings at both ends of the spindle. One end must float axially so the pair of bearings are either held in a floating sleeve or a pair of Duplex bearings are mounted back to back. This makes a total of four bearings per spindle.

A few spindles have been built using more than four bearings for greater capacity and also for greater rigidity obtained by the use of a larger number of balls or points of support. However, this arrangement introduces difficult problems of alignment, eccentricities, and load distribution. It is better to obtain the capacity by using fewer bearings, each having a larger capacity. These multi-bearing spindles usually fall within the class of semi-adjustable or non-adjustable three-bearing spindles.

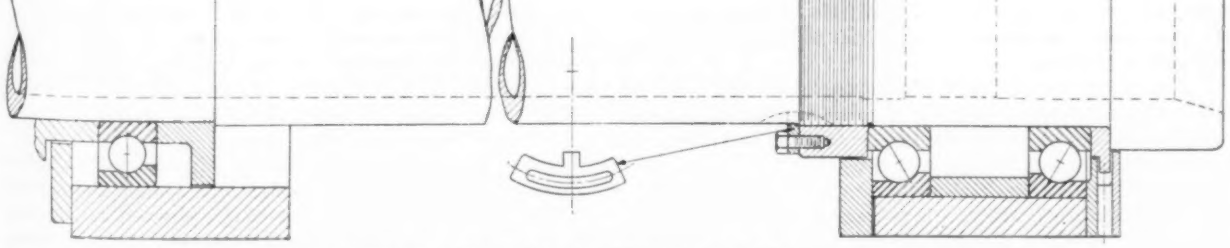

FIG. 15 FULLY ADJUSTABLE THREE-BEARING MOUNTING ON MULTIPLE-SPINDLE AUTOMATIC
(1200 to 1500 lb. initial load.)

bearings with 0.00002 in. maximum eccentricity, and 85 per cent showed no readable movement on a ten-thousandth indicator.

In all of these three-bearing mountings, the far end of the spindle is supported by a bearing that must float endwise in the housing to take care of shaft and housing expansions. The simplest arrangement is a single bearing closely fitted internally,

## CONCLUSIONS

Properly mounted ball-bearing machine-tool spindles have proved unusually rigid. Their main advantages result from this

**increased rigidity and from their ability to maintain their adjustment and accuracy.**

**Rigidity has been obtained by the use of angular-contact or radio-thrust type bearings assembled with relatively large and carefully controlled initial loads to keep them tight.**

**Three general types of mounting design have been developed as outlined above. It is important to select the right type of mounting and the correct bearing size and type to suit the load and service requirements. Sufficient experience is now available to permit intelligent selection.**

## Discussion

F. E. Cardullo.[2] It should prove valuable to have a word from the author as to the relation of the forces in actual practice to the ratings of the bearing. What factors of safety over the rated loads as given in the tables of the manufacturers are employed?

The Author. That is a difficult question and one that requires clarifying in general. Most of the output of the ball-bearing industry is used in the automobile and for that reason, its ratings are based upon automobile service as follows. A 50,000 to 100,000-mile machine with an average speed of 30 miles an hour means 2000 to 4000 hours life and most of the time under less than half the load. The ratings are therefore approximately equal to 1000 hours continuous operation under full load. When the load is cut in half the life increases approximately ten times.

On machine tools, the load varies over a very wide range but we must consider the initial load first. Take, for example, the common size No. A-224. This bearing has a thrust capacity at 300 r.p.m. of about 19,000 lb. We use an initial load of 4000 to 5000 lb. To this we must add about 1000 to 2000 lb. for the *average* load. This will give a safety factor of $3^1/_2$ to 4 with an estimated life of 50,000 to 100,000 hours of actual operation.

The maximum load is determined by the actual rating and can therefore reach well over 18,000 lb.

F. E. Cardullo. In Fig. 13 where a grinder spindle with opposed bearings is shown, these two bearings fitted into the bores and set up with initial tension presumably show no deflection except the elastic deflection of the material. However, on the tail end of the spindle at the pulley, a bearing with no initial tension is shown. How is the radial play at this point removed?

The Author. It is quite important to remove the radial play at the tail end of the spindle. In this case, it is done by providing an initial load within the bearing itself. The balls are made slightly oversize and forced into the bearing. The amount of oversize will vary from 0.0001 to 0.0004 in different cases. This provides the same type of initial load as is obtained at the front pair of bearings.

It may also be done by using a set of duplex bearings back to back when the two inner races are clamped together and initial thrust load is set up within the pair of bearings and then the outer races can float endwise to take care of axial play.

F. E. Cardullo. Fig. 16 shows two oppositely disposed bearings of different sizes, which, it is presumed, are to take care of thrust load. Does not the larger bearing have the lesser strain?

The Author. The larger bearing does have the lesser strain but the larger bearing takes almost all of the load from the work, whereas the small bearing is relieved when thrust is applied from the work. Therefore, it is correct to apply an initial load on the small bearing which is a larger proportion of its total capacity. The small bearing serves only to apply the large initial load. It takes a relatively small proportion of the radial load.

[2] Chief Engineer, G. A. Gray Co., Cincinnati, Ohio. Mem. A.S.M.E.

F. E. Cardullo. In Fig. 14 two bearings of the same size are shown drawn together, the lower one taking the thrust of the drill. Are these two bearings fitted differently so the lower one will take a greater proportion of the raidal load in order to equalize the service on the two bearings?

The Author. The thrust is all taken on the upper bearing of this pair. Pure radial load is divided. A combined load is taken entirely on the upper bearing. The two bearings are exactly identical and no attempt is made to provide a better distribution of the work. The additional economy which would be provided by such a method is not worthwhile.

F. E. Cardullo. Would there by any object in giving the lower bearing a 200 per cent "radio"-thrust matching and the upper one a 100 per cent "radio"-thrust matching?

The Author. This does not prove worthwhile except in the largest spindles like that shown in Fig. 16.

F. E. Cardullo. In Fig. 15, why are the two bearings on the right-hand side so widely separated?

The Author. This is a relatively long and hollow spindle of comparatively thin section. The two bearings on the right-hand end are spread apart to give rigidity to the spindle.

Walter H. Trask, Jr.[3] It would be of value to know if the spindle is treated as a beam fixed at both ends or freely supported and also how much larger must the spindle using ball bearings be than one employing plain bearings?

The Author. The usual ball-bearing support is more nearly analogous to a beam freely supported on the ends. The single-row ball bearing is almost always equivalent to this. However, the double bearing construction used at one end and sometimes both ends on a machine-tool spindle is much more nearly equivalent to a fixed support.

It is true that a ball bearing requires a heavier spindle than a plain bearing, perhaps 10 to 20 per cent larger. However, in most cases, no increase is required because the plain-bearing spindles are made much heavier than necessary. In other words, the minimum size of spindle that can be used with ball bearings should be somewhat larger than the minimum size spindle that can be used with plain bearings.

Note also, that the ball-bearing spindle can be much shorter than the plain-bearing spindle and therefore becomes more rigid in proportion.

Horace B. Schell.[4] Is the bearing shown on the right-hand end of Fig. 16 of the magneto type or open type with the outer race apparently free to float lengthwise in the housing?

The Author. This is not a magento-type bearing. The figure is slightly deceiving. This is the Gurney radial-type bearing where the outer race has a deep groove on one side and a relatively shallow but very definite shoulder on the opposite side. This makes it able to take some thrust in both directions and the outer race is definitely located on the bearing.

Wilson P. Hunt.[5] A particularly difficult problem for the writer's company is to place bearings on extremely close centers with vertical adjustment. In Fig. 16 it is assumed that the head bearing takes all the thrust both ways, and the tail bearing floats to compensate for shaft expansion. Comment on the adjustable bearing should prove valuable.

The Author. If the bearings are required to be close together axially, that is, on a relatively short spindle, it is advisable to use

[3] Mechanical Engineer, Salt Lake Hardware Co., Salt Lake City, Utah. Mem. A.S.M.E.

[4] M. D. Knowlton Co., Rochester, N. Y.

[5] President and Manager, Moline Tool Company, Moline, Ill. Mem. A.S.M.E.

a design like Fig. 1. For example, we mention a billet-peeling machine where bearings are used on a large-diameter spindle of very short length. There are two bearings, one at each end, adjusted against each other as in Fig. 1. There is a rotary tool inside the spindle taking heavy and very rough cut off the outside of billets.

If it is a question of small diameters, we refer to Fig. 15, a multiple-spindle automatic where diameters must be kept down. A three-bearing mounting is then desirable.

The most successful method for obtaining adjustment is to mount the whole spindle housing on a form of way and adjust on the ways. We refer to Fig. 7 which does the same thing to very close tolerances and likewise to Fig. 6. In both of these cases the adjustment is made within thousandths.

F. M. Brauer.[1] Do I understand that as many balls as possible are crowded in without a separator?

The Author. It is 15 to 20 years since bearing manufacturers have realized the absolute necessity of a separator. Bearings without separators are only being used in one or two very special cases. The angular-contact bearing as used in machine tools has particular need for a separator and provides one of the severest separator services. Under combined load, the contact angle of the ball on the races is not constant. It is smaller at the point where the maximum radial load is carried. This means that the ball rides on the inner race on a skewed path, causing a definite variation in ball speed. The separator must take care of this variation in ball speed.

[1] Ordnance Engineer, Watertown Arsenal, Watertown, Mass.

# A Study of Tin-Base Bearing Metals

By O. W. ELLIS[1] and G. B. KARELITZ,[2] EAST PITTSBURGH, PA.

*This study represents the first part of an investigation of babbitts. It comprises the results of metallographic and mechanical tests on a series of tin-antimony-copper alloys containing up to 10 per cent of antimony and 8 per cent of copper. Relationships between the composition, microstructure, hardness, and compressive strength of these alloys are given, and the influences of elevated temperatures and of lead upon these properties are recorded.*

THIS paper concerns itself with an investigation of alloys of tin, antimony, and copper, some of which are used in engineering as bearing metals. This investigation was undertaken with the object of arriving at a logical method of determining which alloys of this system might best serve as bearing metals under any given condition. The present paper covers such work as has so far been accomplished, and shows the relationships which exist between the mechanical properties and the constitution of the alloys of this system of high tin content.

The tin-antimony-copper system has been the subject of considerable investigation, but, apart from a very complete study of the microstructure of the alloys of high tin content by Campbell (Proc. Am. Soc. Test. Mat., 1913, 13, 630) and a somewhat superficial survey of a more extended field of the ternary equilibrium figure by Bonsack (*Zeit. für Metallkunde*, 1927, 19, 109), the results of no systematic inquiry into that portion of the system which includes the bearing metals in more common use have been published.

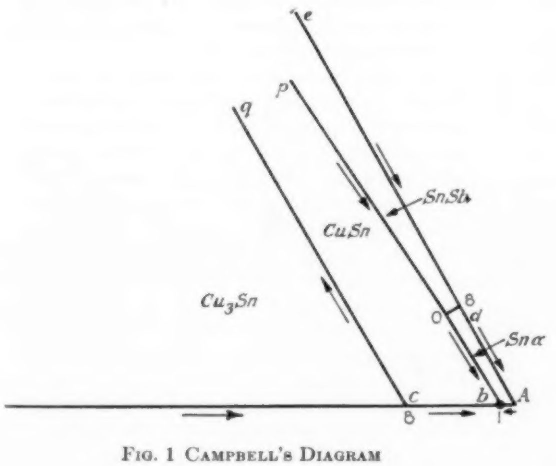


Fig. 1 Campbell's Diagram

To Smith and Humphries (*Jl. Inst. Met.*, 1911, 5, 194), Thompson and Orme (ibid., 1919, 22, 203), Fry and Rosenhain (ibid., 1919, 22, 219), Mahin and Broeker (Proc. Indiana Acad. Sci., 1919, p. 9) and Hudson and Darley (*Jl. Inst. Met.*, 1920, 24, 361) we are indebted for reports on the constitution, structure, and properties of individual alloys of this system, and it may be noted that the authors' conclusions agree in the main with such as are referred to in these and other papers of lesser importance.

### The Tin-Antimony-Copper System

Campbell, in the paper referred to, presented a tentative diagram for the tin end of the system, the main features of which are reproduced in Fig. 1.

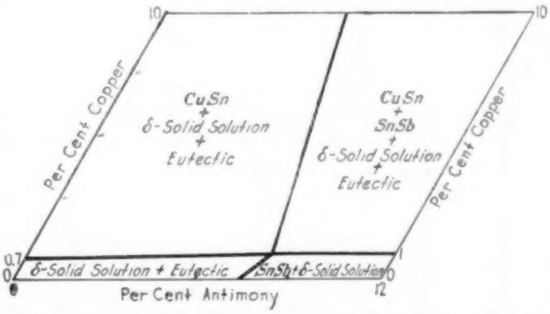


Fig. 2 Structural Characteristics of Tin-Rich Alloys of the Tin-Antimony-Copper System

He divided the alloys into four main groups:

1 Those whose composition fell within the area to the left of the line *qc*, from which $Cu_3Sn$ first separated on freezing
2 Those whose composition fell within the area *pobcq*, from which needles of CuSn first separated on freezing
3 Those whose composition fell within the area *pode*, from which cubes of SnSb first separated on freezing
4 Those whose composition fell within the area *bodA*, whose structure consisted of dendrites or grains of αSn set in the pseudo-eutectic which froze along *ob*.

The authors' plot of this corner of the ternary equilibrium diagram is shown in Fig. 2, which will be seen to differ but slightly from that due to Campbell. It should be noted that the authors have investigated a narrower field.

Fig. 3 Mold Used in Casting Alloys

### General Procedure Employed in Investigation

In arriving at the conclusions embodied in Fig. 2, the authors have been guided by certain of the physical and structural characteristics of a series of alloys covering the entire field of the diagram (Fig. 2).

Two series of 25 alloys each were cast under the conditions referred to later. These alloys were of the compositions quoted in Table 1.[3] They were cast in a mold

[1] Research Department, Westinghouse Elec. & Mfg. Co.

[2] Research Department, Westinghouse Elec. & Mfg. Co. Mem. A.S.M.E.

Part I of a study presented at the Spring Meeting, Pittsburgh, Pa., May 14 to 17, 1928, of The American Society of Mechanical Engineers.

[3] Analyses made by R. H. Wynne, Chemical Section Research Dept., Westinghouse Electric & Mfg. Co.

which was approximately 1.2 in. in internal diameter at the bottom and about 1.3 in. in internal diameter at the top. The length of mold over this tapered portion was about 7.5 in.

TABLE 1 PERCENTAGE COMPOSITION OF ALLOYS INVESTIGATED

| Alloy No. | Nominal Sn | Composition Sb | Composition Cu | Chemical Analysis (1st series) Sb | Chemical Analysis (1st series) Cu | Chemical Analysis (2nd series) Sb | Chemical Analysis (2nd series) Cu |
|---|---|---|---|---|---|---|---|
| 1 | 97.5 | 2 | 0.5 | 2.08 | 0.48 | 2.45 | 0.55 |
| 2 | 97 | 2 | 1 | 2.10 | 1.02 | 2.14 | 1.07 |
| 3 | 96 | 2 | 2 | 2.18 | 2.02 | 2.17 | 2.16 |
| 4 | 94 | 2 | 4 | 2.26 | 3.83 | 2.12 | 4.28 |
| 5 | 90 | 2 | 8 | 2.26 | 7.81 | 2.24 | 6.79 |
| 6 | 95.5 | 4 | 0.5 | 4.29 | 0.47 | 4.88 | 0.54 |
| 7 | 95 | 4 | 1 | 4.26 | 1.05 | 4.25 | 1.07 |
| 8 | 94 | 4 | 2 | 4.02 | 2.02 | 4.11 | 2.11 |
| 9 | 92 | 4 | 4 | 4.02 | 4.00 | 4.17 | 4.26 |
| 10 | 88 | 4 | 8 | 4.14 | 7.50 | 4.28 | 7.70 |
| 11 | 93.5 | 6 | 0.5 | 5.91 | 0.49 | 6.21 | 0.55 |
| 12 | 93 | 6 | 1 | 5.91 | 1.01 | 6.19 | 1.08 |
| 13 | 92 | 6 | 2 | 6.54 | 2.18 | 6.15 | 2.14 |
| 14 | 90 | 6 | 4 | 6.15 | 3.90 | 6.05 | 4.32 |
| 15 | 86 | 6 | 8 | 6.12 | 8.42 | 6.36 | 7.38 |
| 16 | 91.5 | 8 | 0.5 | 8.52 | 0.53 | 8.42 | 0.59 |
| 17 | 91 | 8 | 1 | 7.91 | 1.04 | 8.04 | 1.08 |
| 18 | 90 | 8 | 2 | 8.04 | 2.09 | 8.24 | 2.15 |
| 19 | 88 | 8 | 4 | 8.22 | 3.91 | 8.07 | 4.32 |
| 20 | 84 | 8 | 8 | 8.31 | 7.79 | 8.38 | 7.66 |
| 21 | 89.5 | 10 | 0.5 | 10.17 | 0.53 | 11.01 | 0.67 |
| 22 | 89 | 10 | 1 | 10.05 | 1.06 | 10.23 | 1.09 |
| 23 | 88 | 10 | 2 | 10.11 | 2.08 | 10.18 | 2.15 |
| 24 | 86 | 10 | 4 | 9.86 | 4.03 | 10.16 | 3.72 |
| 25 | 82 | 10 | 8 | 9.71 | 7.72 | 10.18 | 7.03 |

The top of the mold was flared with the object of concentrating any pipe that might form in the top of the casting. A photograph of the mold, which could be separated into two similar halves, is reproduced in Fig. 3. The two halves could be held together by means of a ring, which fitted the outside of the mold snugly.

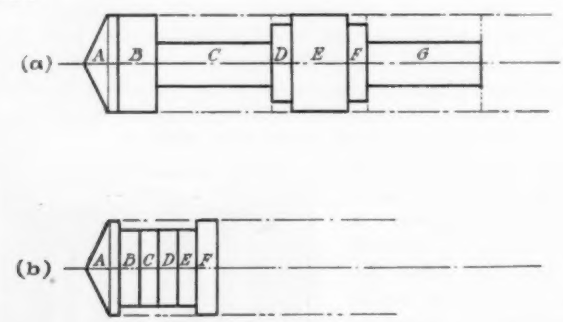


FIG. 4 CUTTING DIAGRAMS FOR TEST BARS

(*a*) A—For microstudy; B—$^1/_2$ in. thick for Brinell test; C and G—$1^1/_2$ in. long × 0.564 in. diam. for compression tests; D and F—1 in. diam. × 0.250 in. thick; E—$^3/_4$ in. thick for hardness tests.
(*b*) B, C, D, and E—1 in. diam. × 0.250 in. thick; F—for microstudy.

The mold was heated to 100 deg. cent. prior to casting. The pouring temperature used was 400 deg. cent.

The castings of the first series were poured into the mold direct from a graphite crucible. From these castings samples were turned for hardness and compression tests, and specimens were taken for chemical, microscopic, thermal, and electrical investigation. The approximate positions in the castings from which the various samples were removed are shown in Fig. 4(*a*).

The castings of the second series were run from a bottom-pouring crucible of steel which was heated electrically and from which the alloys were allowed to flow when at a temperature of 400 deg. cent. The procedure adopted in all cases was to heat the alloy to 425 deg. cent., then to stir the melt thoroughly, and finally to allow it to cool to 400 deg. cent. before tapping; the heating circuit was broken when the pyrometer registered a temperature of 425 deg. cent. The tapping hole in the crucible was $^1/_4$ in. in diameter.

From the castings of the second group samples for analysis, micro-examination, and hardness testing were taken from the points indicated in Fig. 4(*b*).

No trouble was experienced in pouring any of the alloys except those of high copper content. In the case of certain of these alloys, Nos. 5, 10, and 15 in particular, a portion of the melt always remained in the bottom-pouring crucible. Analysis of the material entrapped showed it to be higher in copper content

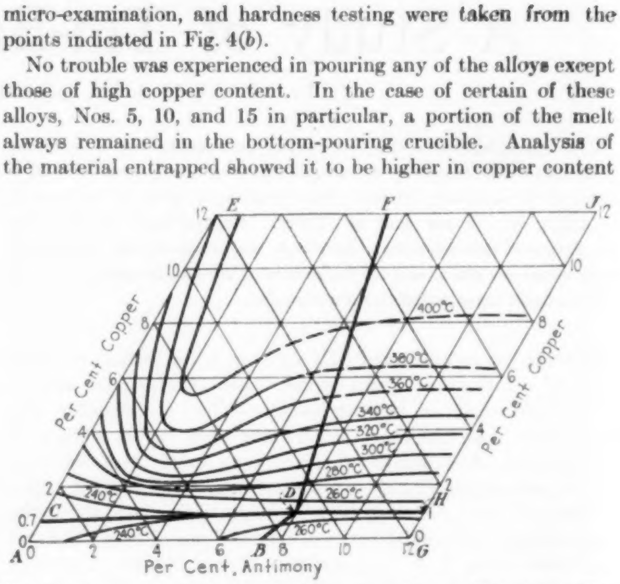


FIG. 5 CONTOURS OF LIQUIDUS SURFACE OF SPACE MODEL FOR TIN CORNER OF SYSTEM

than that which left the crucible to form the castings. A comparison of the microstructure of the two portions of the melt confirmed this. That portion which remained in the crucible, of which Fig. 16 typifies the structure, was characterized by many large crystals of CuSn and a paucity of the tin-rich matrix; the portion which flowed from the crucible into the mold (Fig. 17) contained but few of the coarse crystals of CuSn, and exhibited an almost normal proportion of solid solution.

This effect was more pronounced in the case of alloy No. 10, of which Figs. 16 and 17 are photomicrographs, than in that of the others. An experiment was made in which this alloy was heated to 425 deg. cent. and then tapped from the crucible, but even in this case a part of the apparently liquid mass was retained in the crucible. The amount entrapped was, however, less than that which was held in the crucible at 400 deg. cent.

The reason for this phenomenon was readily explained when the thermal and resistivity curves for these alloys were completed. It then became clear that these alloys, Nos. 5, 10, and 15, were, at 400 deg. cent., below the point at which separation of CuSn from the melt begins on slow cooling, as will be appreciated on reference to Fig. 5, wherein are shown the contours of the liquidus surface—or the surface of temperatures at which CuSn first crystallizes out of the melt—of the space model for the tin corner of this system. The material in the crucible at 400 deg. cent. in the case of these alloys consisted, therefore, of two phases—(1) liquid, which passed through the $^1/_4$-in. tap hole with but little, if any, difficulty, and (2) solid-crystals of CuSn, which settled and collected on the bottom of the crucible as tapping proceeded and of which only such as were in the immediate vicinity of the tap hole during pouring passed through into the mold. These crystals retained a certain amount of liquid, but the amount so prevented from issuing from the mold was relatively small.

In the case of the alloys melted in the graphite crucible and poured at 400 deg. cent. direct into the mold, no large crystals of CuSn were found in the microstructure. The absence of such large crystals is probably due to the fact that opportunity for growth was not given to the CuSn which coexisted with the tin-rich phase at the pouring temperature. When the time occupied by the alloy at temperatures just below the liquidus is prolonged, as was the case with the second series of alloys, excessive growth of CuSn may occur; what the effects upon the mechanical

properties of the material are, however, is unknown. A phenomenon similar to this, in which SnSb played the major role, has been described by Gallagher (*Jl. Phys. Chem.*, 1906, 10, 93) and by Mahin and Broeker (loc. cit.). The fact that such crystal growth can occur at temperatures below the liquidus, the melt being apparently free from the solid phase, is one that should not be overlooked in practice.

### Cooling Curves

Cooling curves were taken of all the alloys of the first series. The changes in electrical resistivity which occurred on slow cooling were also observed. Absolute measurements were not attempted, attention being directed solely to the temperatures at which alterations in resistivity occurred.

It was found that the temperature at which the precipitation of CuSn first occurred on cooling (the liquidus) was subject to considerable variation. It was difficult to prevent supercooling. It was possible, however, to get consistent results, and a close check was obtained between the thermal and electrical values for the liquidi, save in the case of the alloys of maximum copper content, where some dicrepancies arose. Curves typical of those obtained are shown in Fig. 6.

The liquidus values were used in the preparation of Fig. 5, to which attention has already been directed. In this figure the dotted contour lines refer to such portions of the surface of the space model of the system as may require revision on further investigation.

It has been of interest in this connection to compare the authors' results with those of other workers in this field. Thompson (loc. cit.), for example, has quoted 366 deg. cent. as the liquidus of an alloy containing 8.76 per cent of antimony and 4.51 per cent of copper. For an alloy of almost identical analysis Fry and Rosenhain (loc. cit.) have given the temperature 306 deg. cent. for the liquidus. The authors estimate the liquidus of this alloy to be 345 deg. cent., and it appears from this that Thompson's criticism (q.v.) of Fry and Rosenhain's result was justified.

Other values which may be compared are as follows:

| Antimony per cent | Copper per cent | Liquidus—According to authority | Liquidus—According to authors |
|---|---|---|---|
| 4.70 | 1.00 | 235 (*a*) | 243 |
| 8.36 | 3.35 | 320 (*b*) | 318 |
| 8.7 | 2.3 | 252 (*b*) | 265 |

(*a*) Thompson (loc. cit.); (*b*) Hudson & Darley (loc. cit.)

It is felt that the agreement here obtained is very satisfactory, in view of the difficulties which arise due to supercooling.

The authors have found that the solidus—the temperature at which the alloys become completely solid—for all the alloys of this section of the tin-antimony-copper system is 225 deg. cent. the eutectic temperature of the copper-tin system—and that in such alloys as contain SnSb as a separate microconstituent, SnSb begins to crystallize on cooling at an average temperature of 248 deg. cent.

### Microstructure

The microstructure of these alloys as cast is shown in Figs. 7 to 33.

The alloys may be arranged in four groups, according to their microstructure:

*Group 1.* Those alloys which, as cast, are characterized by a hypoeutectic structure comprising the copper-bearing δ-solid solution of the tin-antimony system and the eutectic of the copper-tin system. Figs. 7 (alloy 1), 12 (alloy 6), and 18 (alloy 11) are typical structures of cast alloys of this group. Prolonged annealing of these alloys at 150 deg. cent. effaces this structure and leaves the alloy as a homogeneous δ-solid solution supporting crystallites of CuSn (Fig. 34—alloy 11).

*Group 2.* Those alloys which, as cast, comprise the two microconstituents primary CuSn, δ-solid solution and copper-tin eutectic (Figs. 8, 9, 10, 11, 13, 14, 15, 16, 19, 20, 21, and 22). The proportion of the copper-tin eutectic in these alloys, as in those of group 1, becomes less as the content of antimony increases—cf. Figs. 8, 13, and 19. In these the dark areas represent the eutectic, the light areas the solid solution, and the white needles the primary intermetallic compound, CuSn.

*Group 3.* Those alloys which, as cast, comprise the two microconstituents primary SnSb and δ-solid solution (Figs. 23 and 29). These alloys show no eutectic in their structure, although they do not become completely solid until the eutectic temperature of the copper-tin system has been reached.

*Group 4.* Those alloys which, as cast, comprise the four microconstituents primary CuSn, secondary SnSb, δ-solid solution, and, in some cases, eutectic (Figs. 24, 25, 27, 28, 30, 31, 32, and 33).

These four groups lie within the areas outlined in Fig. 5. Group 1 occupies the area *ABDC*, group 2 the area *CDFE*, group 3 the area *BGHD* and group 4 the area *DHJF*. It will be noted that these four groups differ from those referred to by Campbell,

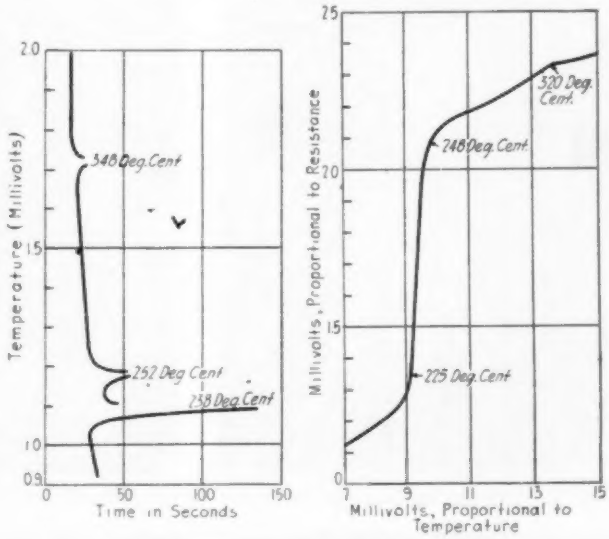


Fig. 6 Typical Cooling Curves

who, however, classified his alloys in accordance with the constituent that first separated from the melt on freezing.

Rapid cooling has the effect of suppressing the crystallization of SnSb at 248 deg. cent. in antimony-rich alloys in the neighborhood of the boundaries *BD* and *DF*. It is therefore possible to obtain a structure free from cubes of SnSb even in such an alloy as No. 18, if the same be cooled from the liquid state at a sufficient rate. This effect in alloy No. 18 is brought out in Figs. 25 and 26, the former representing the average structure toward the center of the ingot, the latter the average structure near the edge. It is possible that this effect might be of some importance in its bearing upon the anti-frictional behavior of the alloys lying near the boundaries *BD* and *DF*, and it may be well to emphasize the fact that the further removed an alloy is from these boundaries the less likely is the normal crystallization of SnSb to be prevented.

The rate of cooling these alloys is, of course, important in its effect on the size of the cubes of SnSb, as has been shown by many observers. The possibility of suppressing the precipitation of

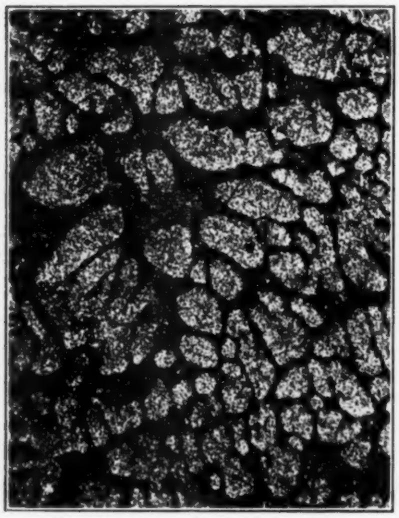

Fig. 7 Alloy No. 1. 150X

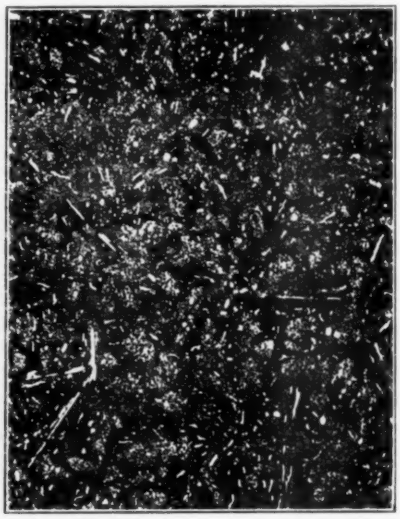

Fig. 8 Alloy No. 2. 150X

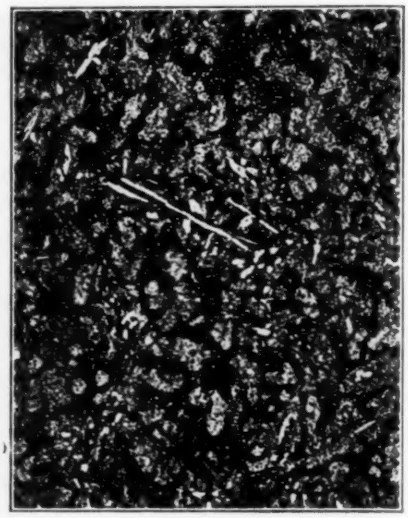

Fig. 9 Alloy No. 3. 150X

Fig. 10 Alloy No. 4. 150X

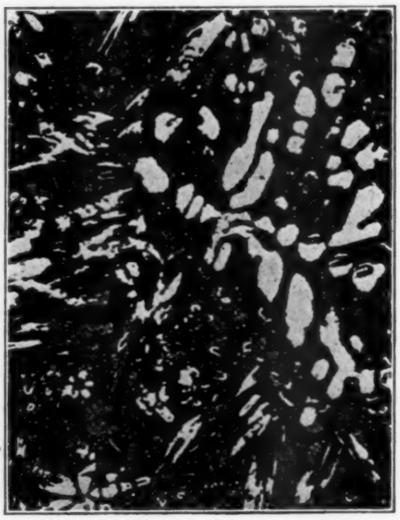

Fig. 11 Alloy No. 5. 150X

Fig. 12 Alloy No. 6. 150X

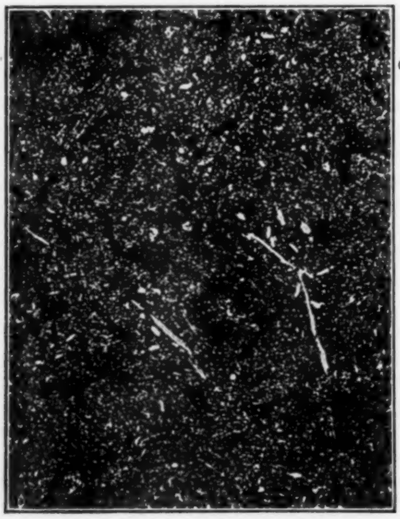

Fig. 13 Alloy No. 7. 150X

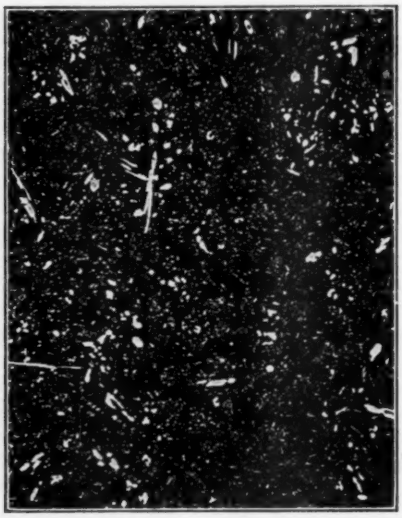

Fig. 14 Alloy No. 8. 150X

Fig. 15 Alloy No. 9. 150X

FIG. 16 ALLOY NO. 10. 150X. PORTION OF MELT WHICH PASSED INTO MOLD

FIG. 17 ALLOY NO. 10. 150X. PORTION OF MELT WHICH WAS RETAINED IN THE MELTING FURNACE

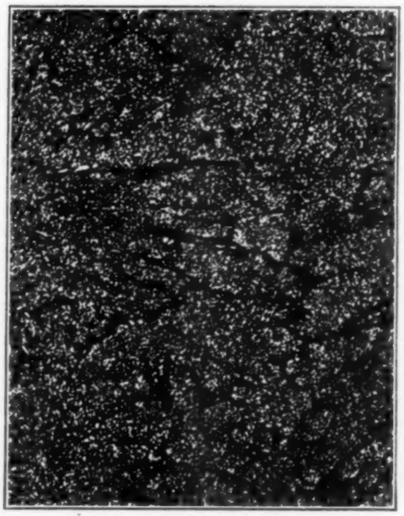

FIG. 18 ALLOY NO. 11. 150X

FIG. 19 ALLOY NO. 12. 150X

FIG. 20 ALLOY NO. 13. 150X

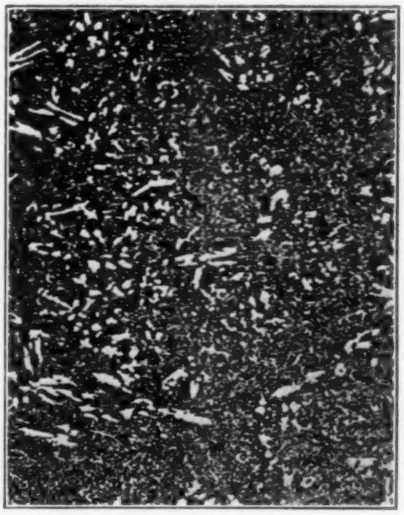

FIG. 21 ALLOY NO. 14. 150X

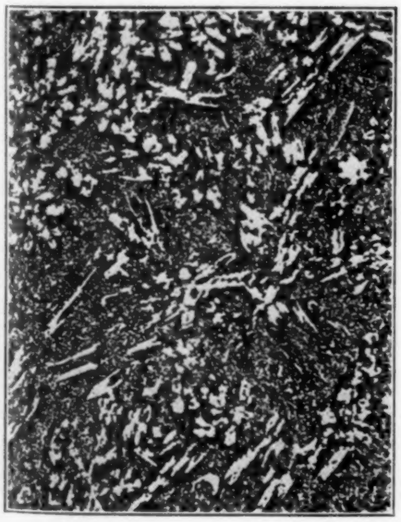

FIG. 22 ALLOY NO. 15. 150X

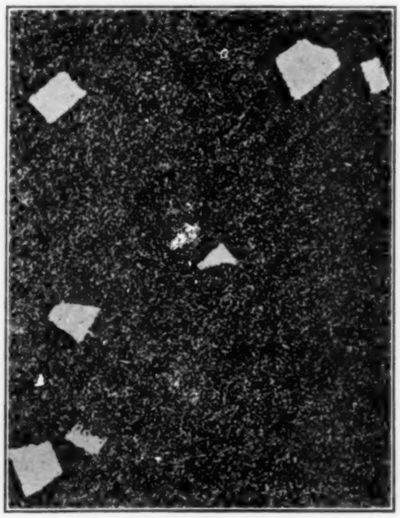

FIG. 23 ALLOY NO. 16. 150X

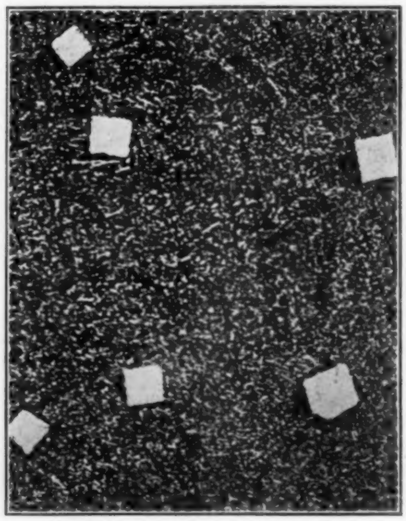

FIG. 24 ALLOY NO. 17. 150X

FIG. 25 ALLOY No. 18. 150X. CENTER OF INGOT

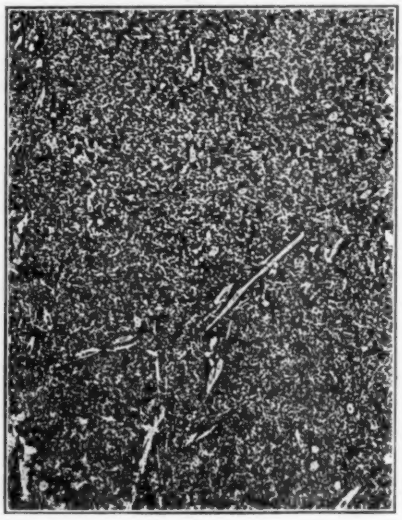

FIG. 26 ALLOY No. 18. 150X. EDGE OF INGOT

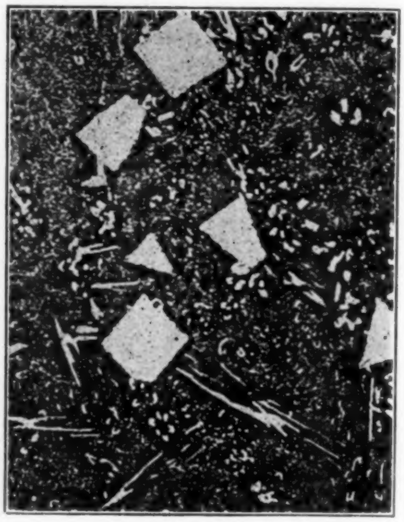

FIG. 27 ALLOY No. 19. 150X

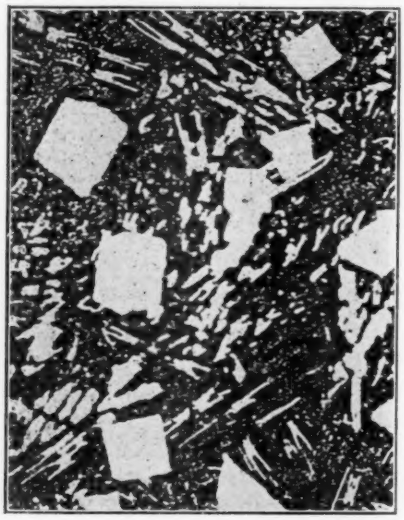

FIG. 28 ALLOY No. 20. 150X

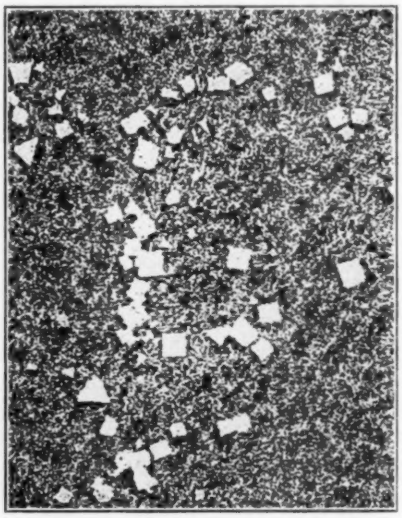

FIG. 29 ALLOY No. 21. 150X

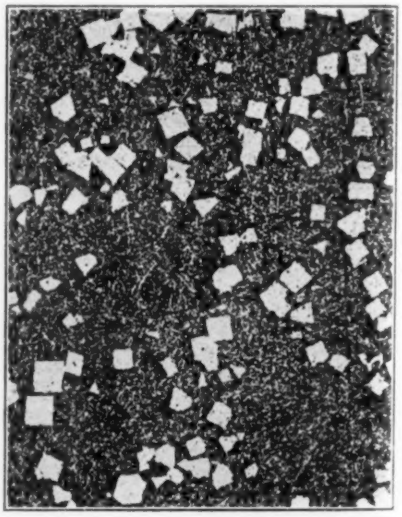

FIG. 30 ALLOY No. 22. 150X

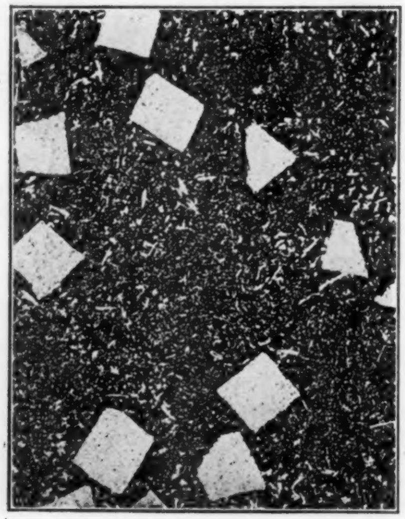

FIG. 31 ALLOY No. 23. 150X

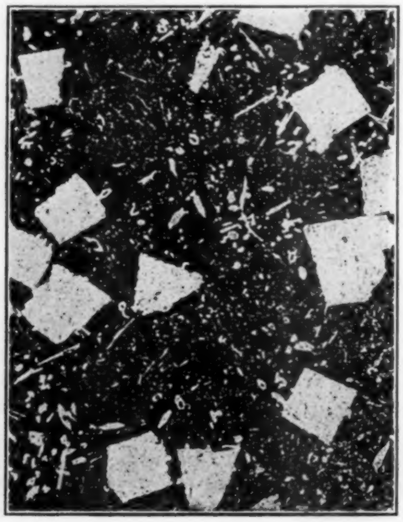

FIG. 32 ALLOY No. 24. 150X

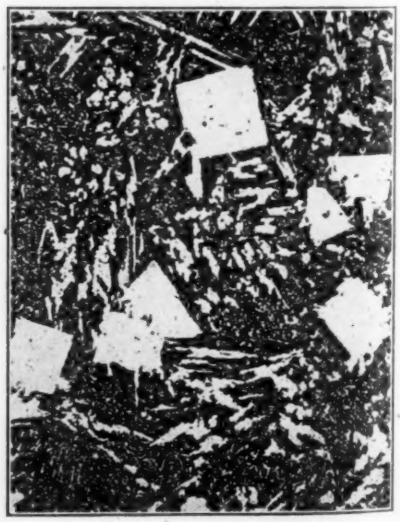

FIG. 33 ALLOY No. 25. 150X

these cubes does not, however, appear to have been referred to in the literature.

Another phenomenon deserving of note is the size of the SnSb cubes in the high-copper alloys as compared with that of the cubes in the low-copper alloys. This is well exemplified in the photomicrographs. If, for example, Figs. 23, 24, and 25 be compared with Figs. 26 and 27, the greater size of the cubes in the high-copper alloys will be appreciated. A comparison for the same purpose may be made between Figs. 29 and 30 and Figs. 31, 32, and 33. In the authors' opinion the difference in crystal size may be accounted for by assuming that the presence of primary CuSn facilitates the precipitation of SnSb and, as a result, a few large cubes are formed where, in the absence of the inoculating medium CuSn, a greater number of small cubes would be precipitated. The presence of needles of CuSn within the cubes of SnSb is a common occurrence in the alloys of high copper content, an occurrence which has been noted by former workers in this field.

### Hardness

Fig. 4(*a*) shows the location of the test pieces cut for investigation of the physical properties of the alloys from the first group of the series. The samples for hardness test were $^3/_4$ in. thick; their diameters were the full diameters of the ingots, that is, 1.25 in., approximately. The hardness was determined on a Brinell machine, a 10-mm. steel ball with a 500-kg. load being used, except when the metal was very soft, in which case a load of 350 kg. was applied to the ball. The load was invariably kept on for a period of 30 sec. for all tests.

Table 2 gives the Brinell hardness of the alloys at room temperature.

TABLE 2 BRINELL HARDNESS OF ALLOYS INVESTIGATED AT ROOM TEMPERATURE[1]

| Antimony, per cent | | Copper, per cent $^1/_2$ | 1 | 2 | 4 | 8 |
|---|---|---|---|---|---|---|
| | Alloy No...... | 1 | 2 | 3 | 4 | 5 |
| 2 | Hardness *a*..... | 9.5 | 11.3 | 12.3 | 13.0 | 15.3 |
| | *b*..... | 9.4 | 11.5 | 11.6 | 13.6 | 17.8 |
| | Alloy No...... | 6 | 7 | 8 | 9 | 10 |
| 4 | Hardness *a*..... | 12.1 | 14.7 | 15.0 | 16.7 | 20.8 |
| | *b*..... | 12.5 | 13.6 | 14.9 | 16.3 | 21.3 |
| | Alloy No...... | 11 | 12 | 13 | 14 | 15 |
| 6 | Hardness *a*..... | 14.6 | 17.0 | 19.2 | 19.5 | 26.6 |
| | *b*..... | 15.6 | 17.2 | 19.3 | 21.4 | 26.5 |
| | Alloy No...... | 16 | 17 | 18 | 19 | 20 |
| 8 | Hardness *a*..... | 18.6 | 19.9 | 21.7 | 21.9 | 26.1 |
| | *b*..... | 19.1 | 19.9 | 20.8 | 23.3 | 27.1 |
| 10 | Alloy No...... | 21 | 22 | 23 | 24 | 25 |
| | Hardness *a*..... | 18.7 | 20.8 | 20.8 | 22.6 | 30.4 |
| | *b*..... | 20.1 | 20.9 | 20.8 | 23.8 | 30.5 |

[1] The room temperature during these tests was 21.5 deg. cent. for set *a*, and 26 deg. cent. for set *b*.

Values marked *a* were obtained on the E test pieces [Fig. 4(*a*)]; those marked *b* were check tests determined on the B pieces [Fig. 4(*a*)]. The observations on the E and B pieces agreed within the limits of experimental error.

A three-dimensional figure of the hardness at room temperature as a function of the copper and antimony content is given in Fig. 34, while in Fig. 35 these data are presented in a diagram of lines of equal hardness (isoscleric diagram). Both diagrams are based on the measurements of hardness of the first group. The regions of the four different types of microstructure are shown by dotted or heavy lines.

It will be noted from the general character of the curves that addition of antimony beyond the line of separation of tin-antimony crystals (approximately 7.5 per cent antimony) increases the hardness but slightly, at least in the field covered by the authors' investigation. The hardness of the Straits tin which was used as the basis of the authors' alloys was found to be 5.0.

The data obtained by the authors may be compared (Table 3) with those given in other papers. J. R. Freeman, Jr., and R. W. Woodward in Technologic Paper No. 188 of the Bureau of Standards, and J. R. Freeman, Jr., in the Proceedings of the American

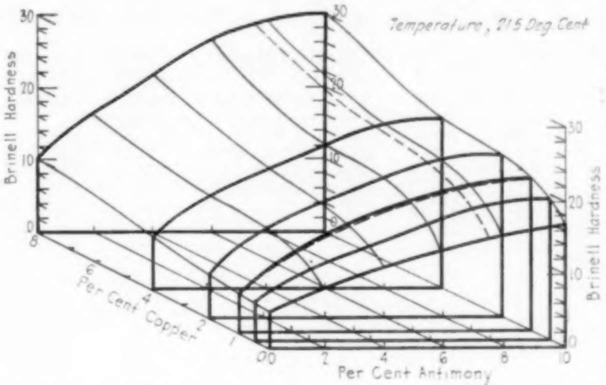


Fig. 34 Three-Dimensional Figure of Hardness at Room Temperature as a Function of the Copper and Antimony Content

Society for Testing Materials, vol. 22, 1922, p. 207, give Brinell hardness numbers for alloys which lie within the range of the authors' experiments.

TABLE 3 BRINELL HARDNESS NUMBERS OF ALLOYS GIVEN IN OTHER PAPERS

| No. of alloy | Copper, per cent | Antimony, per cent | Hardness as given | Authors' data by interpolation |
|---|---|---|---|---|
| A.S.T.M. No. 1 | 4.56 | 4.52 | 17.2 | 18.5 |
| A.S.T.M. No. 2 | 3.51 | 7.57 | 24.3 | 22.8 |
| S.A.E. No. 11 | 5.65 | 6.90 | 22.3 | 22.5 |

This appears to be a satisfactory agreement.

### Hardness at Elevated Temperatures

In order to determine the softening action of elevated temperatures on the alloys, a small electric furnace was built (Fig. 36)

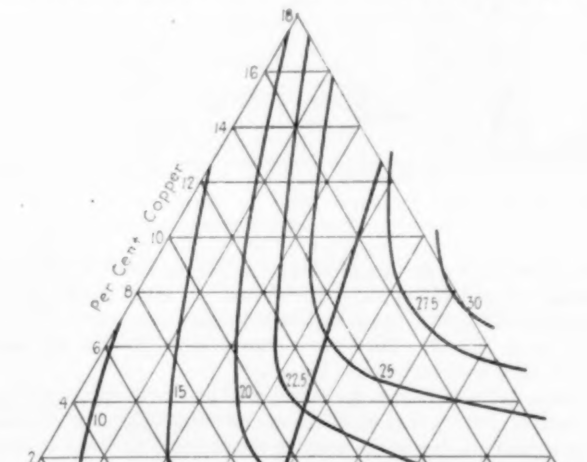


Fig. 3 Isoscleric Diagram for Varying Copper-Antimony Proportions

of a size small enough for it to rest on the anvil of the Brinell testing machine. The samples were placed in a glycerine bath, the temperature of which could be regulated by changing the current in the heating element. The bath was equipped with a stirrer and thermometer.

The Brinell numbers for temperatures ranging from 1 deg. cent. (melting ice and water in the bath of the furnace) to 125 deg. cent. were determined and are given in Table 4. The numbers printed in italics were obtained with a load of 350 kg. on the 10-mm. ball, the material being too soft for the use of a 500-kg. load. Figs. 37–41 and 42–46 show the hardness plotted against

TABLE 4 BRINELL NUMBERS OF ALLOYS FOR TEMPERATURES RANGING FROM 1 DEG. CENT. TO 125 DEG. CENT.

(Values in italics obtained with a load of 350 kg. on the 10-mm. ball)

| Copper, per cent | Deg. cent. | Antimony, per cent: 2 | 4 | 6 | 8 | 10 |
|---|---|---|---|---|---|---|
| 0.5 | 1 | 10.9 | 14.6 | 18.6 | 21.7 | 21.8 |
| | 21.5 | 9.5 | 12.1 | 14.6 | 18.6 | 18.7 |
| | 50 | .. | 9.3 | 11.2 | 14.4 | 15.2 |
| | 75 | *5.9* | *8.3* | 8.3 | 10.6 | 11.9 |
| | 100 | *5.0* | *5.9* | *8.3* | 7.4 | 8.1 |
| | 125 | *3.5* | *4.9* | *6.5* | *7.5* | *7.5* |
| 1 | 1 | 13.7 | 17.1 | 19.0 | 22.7 | 23.6 |
| | 21.5 | 11.3 | 14.7 | 17.0 | 19.9 | 20.8 |
| | 50 | 7.1 | 11.7 | 13.3 | 16.6 | 16.7 |
| | 75 | *7.3* | 9.0 | 10.0 | 10.9 | 11.5 |
| | 100 | *5.2* | .. | 7.8 | 9.9 | 10.2 |
| | 125 | *4.6* | *6.5* | *6.8* | *7.9* | *8.6* |
| 2 | 1 | 13.3 | 17.7 | 22.2 | 24.8 | 24.7 |
| | 21.5 | 12.3 | 15.0 | 19.2 | 21.7 | 20.8 |
| | 50 | 8.5 | 10.7 | 14.5 | 16.2 | 15.8 |
| | 75 | *7.5* | 8.1 | 11.1 | 13.2 | 13.8 |
| | 100 | *5.7* | 5.9 | 8.6 | 10.2 | 9.0 |
| | 125 | *4.6* | *5.9* | *7.6* | *8.1* | *8.4* |
| 4 | 1 | 14.9 | 18.8 | 22.7 | 25.9 | 26.6 |
| | 21.5 | 13.0 | 16.7 | 19.5 | 21.9 | 22.6 |
| | 50 | 9.5 | 12.6 | 14.9 | 17.2 | 18.8 |
| | 75 | *8.6* | 9.9 | 11.7 | 14.5 | 14.6 |
| | 100 | *6.5* | *8.1* | 7.6 | 9.8 | 11.1 |
| | 125 | *4.9* | *6.4* | *8.3* | *9.1* | *10.1* |
| 8 | 1 | 20.0 | 30.3 | 32.4 | 30.9 | 32.6 |
| | 21.5 | 15.3 | 20.8 | 26.6 | 26.1 | 30.4 |
| | 50 | 12.9 | 17.0 | 19.1 | 21.4 | 23.4 |
| | 75 | 11.5 | 12.3 | 14.6 | 15.8 | 17.4 |
| | 100 | 8.7 | 8.7 | 13.7 | 13.0 | 13.5 |
| | 125 | *6.3* | *9.4* | *10.9* | *10.8* | *11.9* |

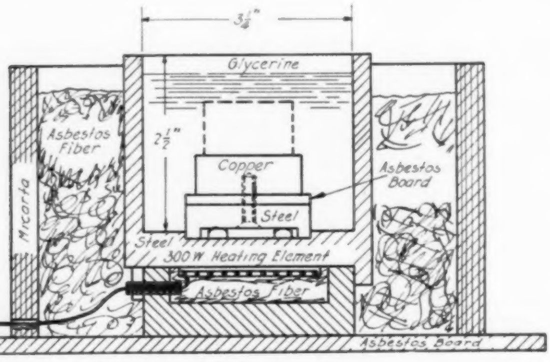


FIG. 36 ELECTRIC FURNACE USED IN DETERMINING SOFTENING ACTION OF ELEVATED TEMPERATURES

temperature for groups of alloys containing equal amounts of antimony and of copper, respectively. A space model of the hardness of the 25 alloys at various temperatures was prepared and is show in Fig. 47. The surface corresponding to 21.5 deg. cent. is the same as that shown in Fig. 34.

Since babbitt linings are often working at temperatures between 70 and 90 deg. cent. the considerable difference between the Brinell number at the working temperature and that at room temperature is very important. It seems advisable to specify hardness of the bearing metal both at room and at elevated temperatures.

## COMPRESSION TESTS

Two compression test pieces were cut from each ingot of the first group of alloys. These are denoted as C and G; by comparing the compression test data for these two samples, taken from the upper and lower portions of the castings, respectively, it was possible to judge the uniformity of the material of the castings. The shape of the test pieces was based by the authors on the investigation of J. R. Freeman, Jr., and P. F. Brandt reported in a paper entitled "The Influence of the Ratio of Length to Diameter in the Compression Testing of Babbitt Metals," in Proc. A.S.T.M., vol. 23 (1923), part II, p. 150. This paper showed that the stress-deformation curves for these metals are the same when the ratio of the length to the diameter of the test piece lies between 3 to 1 and 1 to 1, and that the gage length may be either a part or the whole length of the test sample. In another paper by Mr. Freeman (Proc. A.S.T.M., vol. 22 (1922), part I, p. 207) it was demonstrated that the results of tests do not vary, for babbitt metals, when test pieces of 1-in. or $^1/_2$-in. diameter are used. The authors therefore adopted compression test pieces $1^1/_2$ in. long by 0.564 in. diameter, which gives a 0.25-sq. in. cross-sectional area.

The compression tests were made in an Amsler testing machine of 20,000 lb. maximum capacity. The test piece was compressed between two hardened polished steel plates. An initial load of 50 lb. was applied to take up slack motion in the set-up, and the load was increased gradually at a rate of 100 lb. per min. for all the alloys. The tests were continued till a compression of 0.375 in. or 0.250 in. per inch length of the test piece was attained; the corresponding load was considered as the "ultimate load." An autographic record of the stress-deformation curve was taken on the machine, and accurate readings of the deformation were taken by means of dial gages showing the motion of the plunger of the Amsler machine. Readings were taken at every 50 lb. till 600 lb. load was reached, and subsequently at every 100 lb.

Fig. 48 shows the stresses plotted against deflections for the initial part of the compression of the samples cut from the ingot of alloy No. 9. The upward bend at the lower end of the curves is probably caused by the elasticity of the parts of the Amsler machine. The stresses 3100 and 2690 lb. per sq. in. were taken to be the proportional limits of the two samples. It should be noted that the alloys have no proportional limit in the strict sense of the word, since the point where the curve deviates from a straight line will differ, depending on the scale to which the deflections are plotted. All test data were plotted to the same scale as in Fig. 48, and either the apparent end of the straight-line portion or the point of maximum slope of the curve in case no such line existed, was called by the authors the "proportional limit." Determinations were also made of arbitrarily chosen yield points of these alloys, these yield points being taken as the stresses corresponding to the points of intersection of the initial straight portions of the load-compression curves and the tangents

TABLE 5 ULTIMATE STRENGTHS, PROPORTIONAL LIMITS, AND YIELD POINTS OF THE ALLOYS TESTED, IN LB. PER SQ. IN.[1]

| Antimony, per cent | | Copper, per cent: 0.5 | 1 | 2 | 4 | 8 |
|---|---|---|---|---|---|---|
| | No. | 1 | 2 | 3 | 4 | 5 |
| 2 | U.S. | 7,560 | 8,540 | 8,880 | 10,000 | 12,080 |
| | P.L. | 1,580 | 1,590 | 1,960 | 1,860 | 2,200 |
| | Y.P. | 4,380 | 5,160 | 5,880 | 6,880 | 7,220 |
| | No. | 6 | 7 | 8 | 9 | 10 |
| 4 | U.S. | 9,360 | 10,680 | 10,920 | 12,020 | 13,500 |
| | P.L. | 2,355 | 2,490 | 2,450 | 2,890 | 3,155 |
| | Y.P. | 5,660 | 7,080 | 7,060 | 8,300 | 10,840 |
| | No. | 11 | 12 | 13 | 14 | 15 |
| 6 | U.S. | 11,500 | 12,880 | 13,480 | 14,040 | 16,400 |
| | P.L. | 3,390 | 3,140 | 3,380 | 3,540 | 4,795 |
| | Y.P. | 7,100 | 7,500 | 8,800 | 9,700 | 12,660 |
| | No. | 16 | 17 | 18 | 19 | 20 |
| 8 | U.S. | 13,960 | 14,260 | 15,180 | 15,560 | 16,880 |
| | P.L. | 3,230 | 3,605 | 3,790 | 4,520 | 4,070 |
| | Y.P. | 8,640 | 8,860 | 9,920 | 11,340 | 13,480 |
| | No. | 21 | 22 | 23 | 24 | 25 |
| 10 | U.S. | 13,840 | 14,000 | 14,420 | 16,040 | 18,420 |
| | P.L. | 3,560 | 3,630 | 4,460 | 4,880 | 5,670 |
| | Y.P. | 8,240 | 9,440 | 9,780 | 11,920 | 14,580 |

[1] It may be of interest to note the corresponding values for Straits tin, which are as follows: U.S., 4480; P.L., 1820; Y.P., 2420 lb. per sq. in.

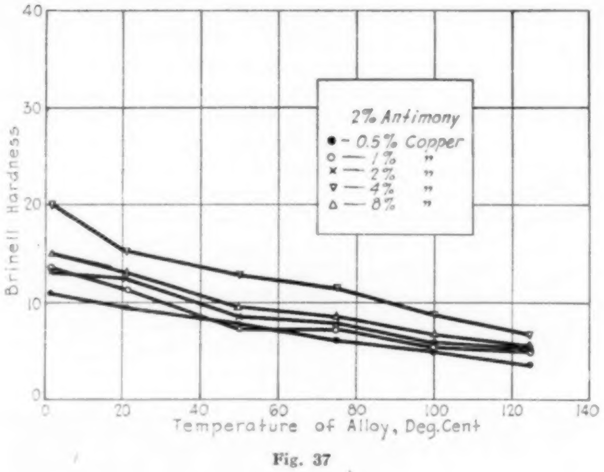


Fig. 37

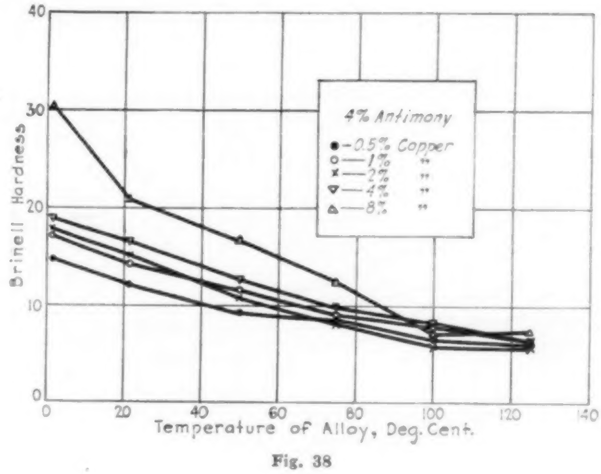


Fig. 38

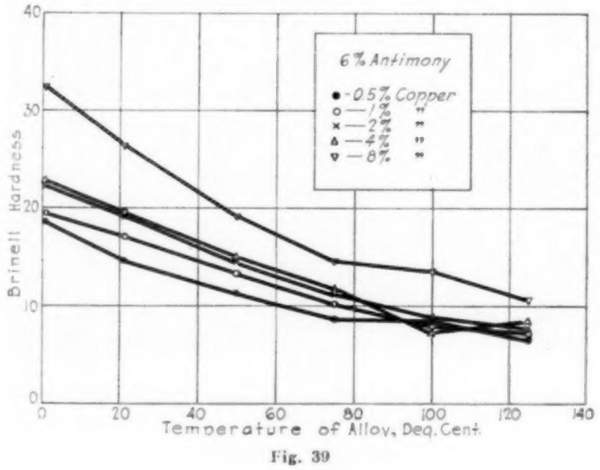


Fig. 39

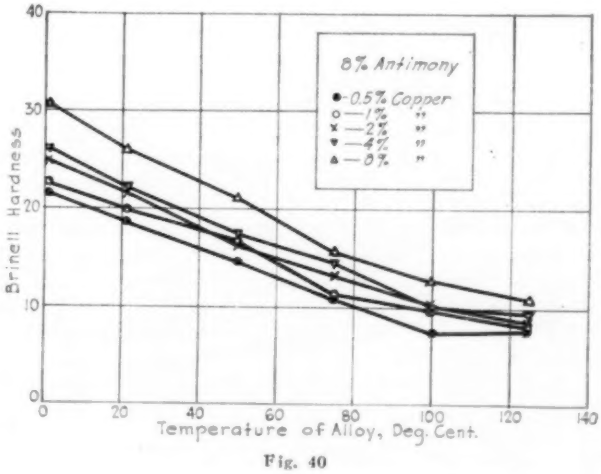


Fig. 40

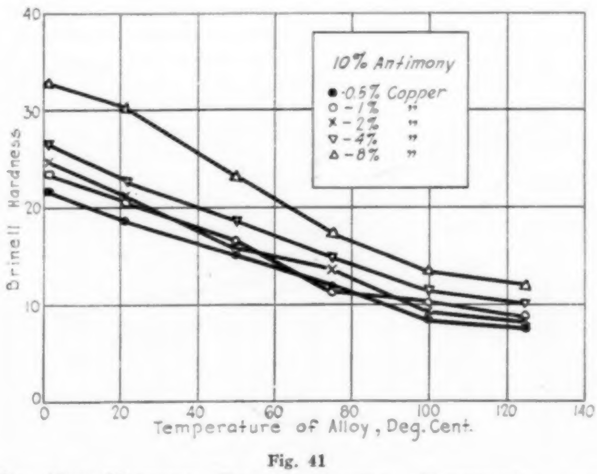


Fig. 41

FIGS. 37–41 HARDNESS PLOTTED AGAINST TEMPERATURE FOR GROUPS OF ALLOYS WITH EQUAL AMOUNTS OF ANTIMONY

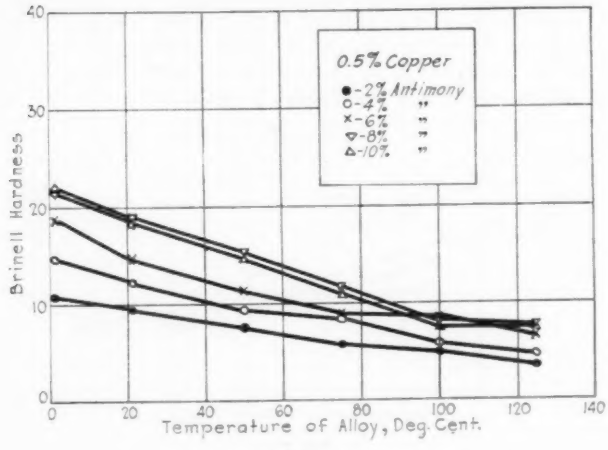


Fig. 42

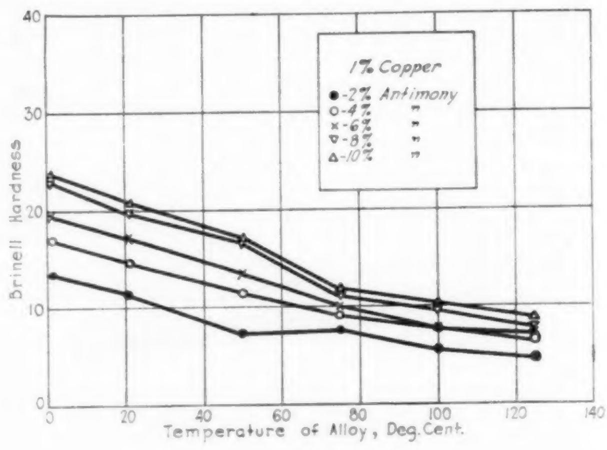


Fig. 43

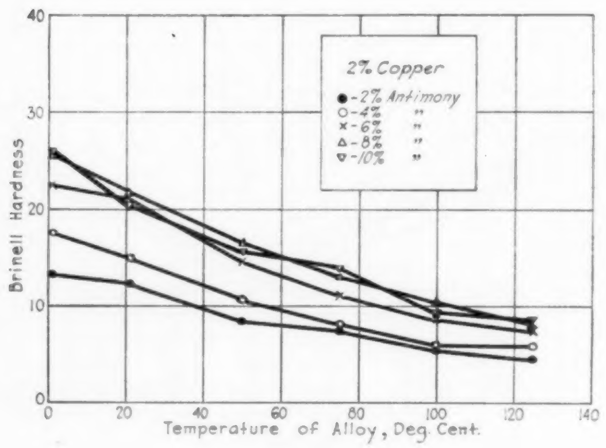


Fig. 44

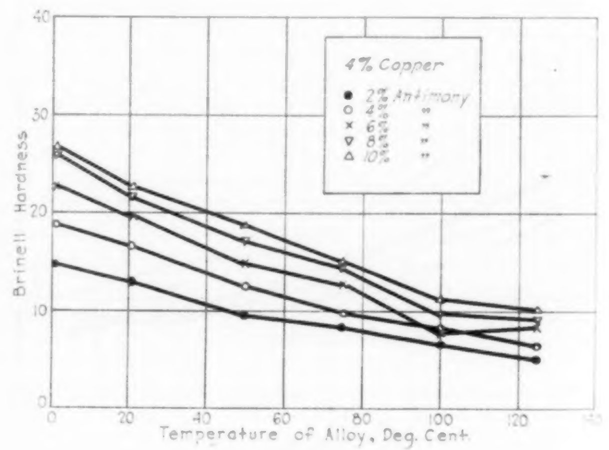


Fig. 45

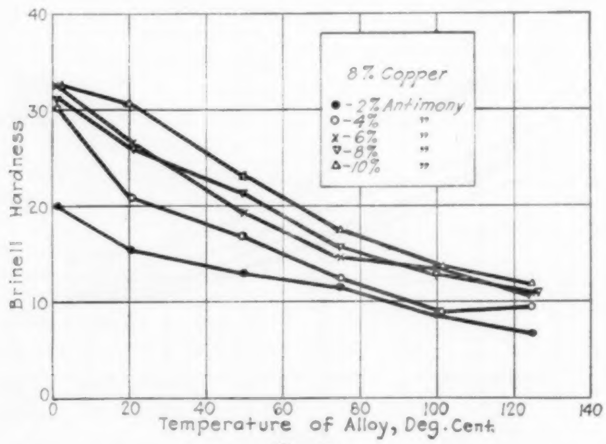


Fig. 46

Figs. 42–46 Hardness Plotted Against Temperature for Groups of Alloys With Equal Amounts of Copper

to these curves at the points corresponding to 0.375 in. compression. Determinations of the proportional limits and yield points of these alloys cannot be made with the same degree of accuracy as can those of the ultimate strength, which is measured directly on the dial gage of the machine; nevertheless these values obtained from the load-compression diagram for these alloys are given in Table 5. These values represent the characteristics of these alloys at room temperatures ranging from 21 to 26 deg. cent., the stresses quoted being the average of those obtained for the bottom and top test samples.

Copies of the autographic load-compression charts are given in Figs. 49 and 50. In Fig. 49 the curves are grouped according to the content of antimony, those for the samples taken from the bottom and top of the ingots being superimposed; the coincidence between the curves is very satisfactory. In Fig. 50 the

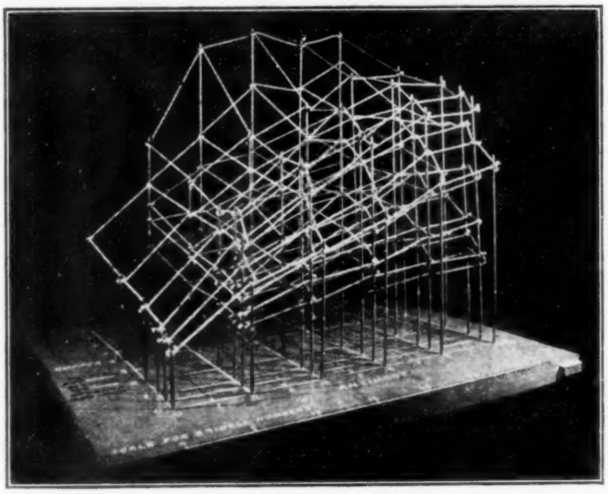

Fig. 47 Space Model of Hardness of the 25 Alloys at Various Temperatures

curves for the bottom pieces only are given; they are grouped according to the content of copper. A peculiar feature is noticeable when the two figures are compared: in Fig. 49 the curves in each group with equal amounts of antimony are fairly parallel, i.e., of equal slope, in the region of plastic deformation, while in Fig. 50 the curves for alloys with the same amount of copper, but different contents of antimony are divergent, the slopes increasing with increase in antimony content. This may be explained by the fact that the crystallites of CuSn are in the shape of small needles, while those of SnSb are in the form of comparatively large cubes. Although the needles add greatly to the initial strength of the metal, when internal slipping occurs the needles of CuSn are not so effective in preventing further flow as are the cubes of SnSb.

The babbitt may be aptly compared with a plastic clay in which are incorporated numerous small splinters and larger cubes of wood. When stress is applied to this clay, both the splinters and cubes help it to

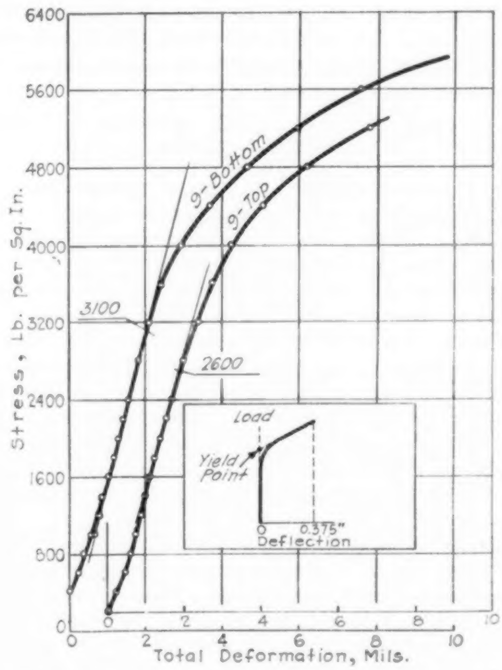


Fig. 48 Stresses Plotted Against Deflections for the Initial Stage of Compression of Samples Cut From Ingot of Alloy No. 9

resist deformation. At a certain stage of deformation, however, the splinters, which initially offered mutual support to one another and thus greatly influenced the strength of the mass as a whole, become disturbed, and, being thus disconnected and relatively small, fail to prevent effectively the further deformation of the clay. The larger cubes, however, due to their shape and size, still act as keys to inhibit slip.

The differing actions of copper and tin in the babbitt are also interestingly demonstrated in the photograph, Fig. 51, of the test pieces after 25 per cent compression. The surface of the test pieces with high copper content are rather smooth when compared with those of low copper content. The low-copper samples in all cases have the same superficial appearance as that of the Straits tin, which is shown on top of an uncompressed piece in Fig. 51. This may be explained by assuming that the interlocking needles of CuSn so break up the structure of the

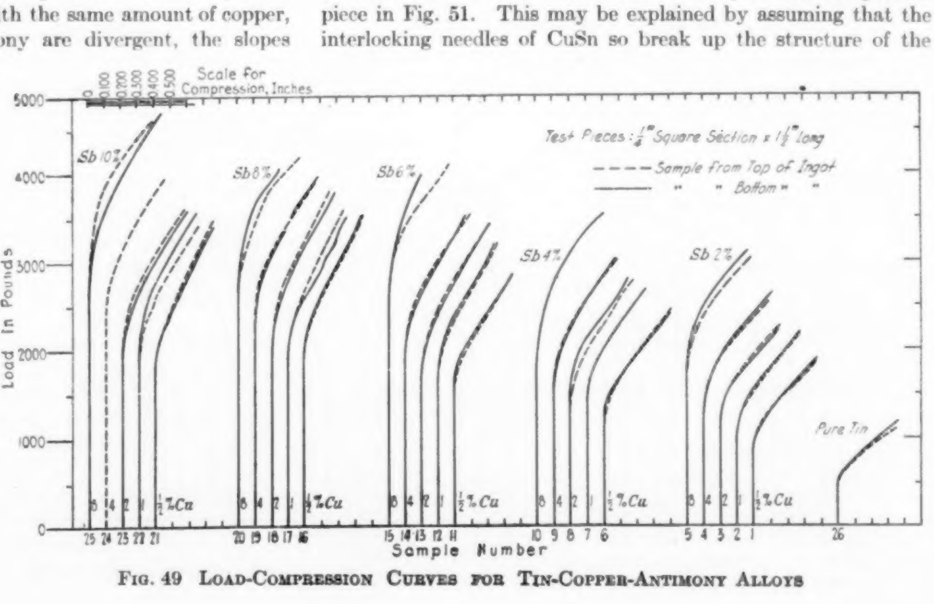


Fig. 49 Load-Compression Curves for Tin-Copper-Antimony Alloys

alloy that slip of relatively minute blocks only can occur, whereas in the absence of these needles movement of comparatively large sections of the metal can take place, resulting in a rough surface of the sample after compression.

### Relation Between Compressive Strength and Brinell Hardness

Since it is much quicker and easier to test a babbitt metal for Brinell hardness than for compressive strength, the relation between the two tests was investigated by the authors, and a satisfactory correlation of results was found.

Fig. 52 shows the relation between the ultimate strength of the alloys and their hardness, both at room temperature. The points fall on a definite curve, the deviation of the points being within the limits of experimental errors. The plotting of the proportional limits and the yield points against the Brinell hardness (Figs. 52 and 53) shows a certain relation, although the points are more scattered. This is natural, since the proportional limits and yield points are obtained by an arbitrary method. It seems reasonable to adopt the straight-line relation shown in Figs. 52 and 53.

It should be noted that the authors do not imply that there is any logical reason to expect a definite correlation between compressive strength and Brinell hardness, and the relations given are merely a convenient empirical way to derive the strength of babbitts from Brinell tests. This is especially important when the strength at elevated temperatures is sought, since, having the Brinell number the ultimate strength, proportional limit, and yield point may be found and the approximate stress-compression curve may be constructed.

The 12 standard white bearing metals of the A.S.T.M. were tested by J. R. Freeman, Jr. (loc. cit.), the hardness and ultimate strength of the metals at 20 deg. cent. and 100 deg. cent. being given. Table 6 gives a comparison between the ultimate strengths found by Mr. Freeman and the values obtained by scaling off from the curve in Fig. 52. It is worthy of note that a close agreement exists, not only between the two sets of values for the tin-antimony-copper alloys at 20 deg. cent., but for the lead-base alloys as well. The agreement is not so close in the case of the 100-deg. cent. values, but it may be observed that Freeman in his hardness tests used a 500-lb. load, and at a temperature of 100 deg. cent. such a load is excessive and readily leads to inaccurate readings.

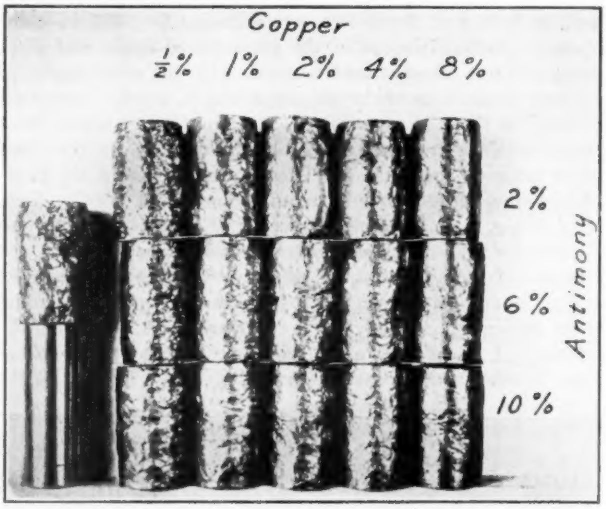


Fig. 51 Superficial Appearance of Test Pieces After 25 Per Cent Compression

TABLE 6 COMPARISON OF ULTIMATE STRENGTHS FOUND BY FREEMAN WITH VALUES SCALED FROM FIG. 52

| | Per cent | | | | 20 deg. cent. | | | 100 deg. cent. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Bearing metal No. | Sn | Sb | Cu | Pb | Hardness | U.S. as found in B. of Stds. | U.S. from Fig. 52 | Hardness | U.S. as found in B. of Stds. | U.S. from Fig. 52 |
| 1 | 91 | 4.5 | 4.5 | | 17.2 | 12,850 | 12,600 | 8.2 | 6950 | 6,800 |
| 2 | 89 | 7.5 | 3.5 | | 24.3 | 14,920 | 16,620 | 12.2 | 8680 | 9,600 |
| 3 | 83 1/3 | 8 1/3 | 8 1/3 | | 27.2 | 17,590 | 17,800 | 14.6 | 9890 | 11,100 |
| 4 | 75 | 12 | 3 | 10 | 24.3 | 16,160 | 16,620 | 11.9 | 6900 | 9,400 |
| 5 | 65 | 15 | 2 | 18 | 22.3 | 15,030 | 15,650 | 10.2 | 6730 | 8,200 |
| 6 | 20 | 15 | 1.5 | 63.5 | 20.8 | 14,530 | 15,040 | 10.5 | 8050 | 8,500 |
| 7 | 10 | 15 | | 75 | 22.7 | 15,640 | 15,820 | 10.5 | 6170 | 8,500 |
| 8 | 5 | 15 | | 80 | 19.8 | 15,620 | 14,340 | 9.6 | 6160 | 7,800 |
| 9 | 5 | 10 | | 85 | 19.1 | 14,710 | 13,750 | 8.5 | 5850 | 7,100 |
| 10 | 2 | 15 | | 83 | 17.3 | 15,430 | 12,900 | 9.2 | 5770 | 7,500 |
| 11 | | 15 | | 85 | 15.0 | 12,820 | 11,500 | 7.0 | 5100 | 6,000 |
| 12 | | 10 | | 90 | 14.6 | 12,880 | 11,200 | 6.6 | 5100 | 5,700 |

### Influence of Small Admixtures of Lead

For two reasons it became clear that a study of the effect of lead on the microstructure and properties of certain of these alloys would be advisable. In the first place, the use of commercial tin containing lead and copper is not uncommon. In the second place, the tinning of bearing shells prior to babbitting generally involves the use of a tin-lead solder, and as a result contamination of the lining with lead is unavoidable.

To investigate the effect of lead upon the properties of typical tin-base bearing metals two groups of alloys were prepared of the following analyses:

| | Group 1 | | | |
|---|---|---|---|---|
| | Sb | Cu | Pb | Sn |
| *a* | 7.90 | 1.39 | 0.72 | diff. |
| *b* | 8.02 | 2.02 | 1.18 | |
| *c* | 7.93 | 2.00 | 1.81 | |
| *d* | 7.84 | 2.00 | 2.33 | |

| Group 2 | | | |
|---|---|---|---|
| Sb | Cu | Pb | Sn[1] |
| 8.65 | 8.336 | 0.82 | diff. |
| 7.93 | 8.18 | 2.69 | |

[1] Very small amounts of other impurities also.

Group 1 is a series of alloys having alloy No. 18 as a base, lead having been substituted for tin in this alloy.

Group 2 is a series of alloys

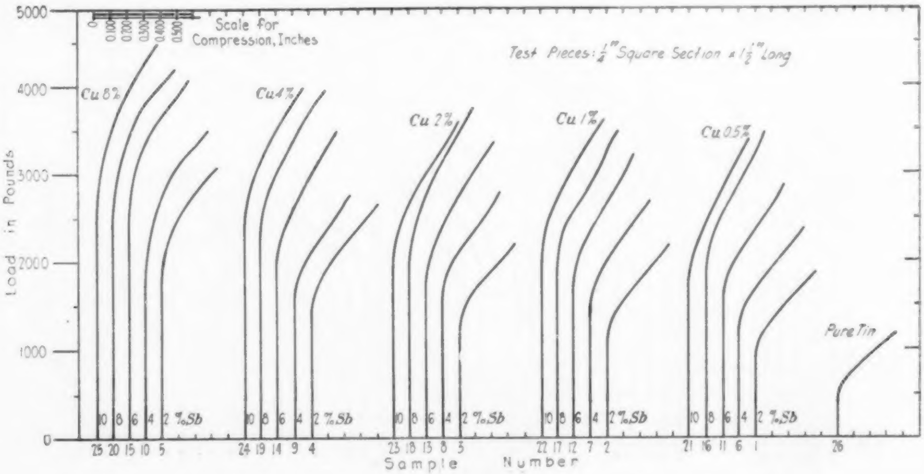


Fig. 50 Load-Compression Curves for Tin-Copper-Antimony Alloys

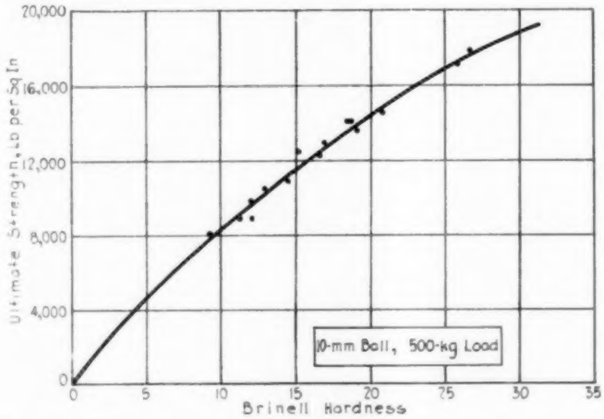


Fig. 52 Relation Between Ultimate Strength and Hardness of Alloys at Room Temperature

having alloy No. 20 as a base, lead again having been substituted for tin.

These were examined microscopically and hardness and compression tests were made. The effect of temperature on hardness was also studied. The cooling curves of these alloys exhibited a deflection at 181 deg. cent. in addition to those noted in the lead-free mixtures. This, no doubt, was due to the presence of traces of the eutectic of the lead-tin system. Such an evolution of heat has been referred to by Cowan (Institute of Metals—Advance Copy No. 451—subject to revision), who has shown also that the presence of lead in these alloys results in the formation of minute shrinkage cavities due to the freezing out of the lead tin eutectic at 181 deg. cent.

Photomicrographs of alloys *b* and *c* of Group 1 are shown in Figs. 55 and 56. These may be compared with Fig. 25, which shows the structure of lead-free alloy of about the same composition. It appears from these photographs that the substitution of lead for tin in alloys of low copper content has the effect of causing the CuSn needles to crystallize in a massive form. It has the further effect of pushing the lines *BD* and *DF* of the ternary equilibrium diagram away from the tin corner of the system. This effect is made evident by the almost complete absence of cubes of SnSb from the structure of alloy *d*.

It is not improbable that the deleterious effect of lead upon the malleability and shock-resisting qualities of certain of these alloys, which have been frequently referred to in the literature, is due to the manner in which the CuSn crystals separate from the melt. The authors, however, have no conclusive argument at the moment either for or against the evidence which has appeared in regard to the effect of lead on the brittleness of these metals.

Typical structures of alloys *a* and *b* of group 2 are shown in Figs. 57 and 58. In these alloys the coarsening effect of lead upon the CuSn constituent is not so marked, but the tendency of lead to extend the area of the δ-field of the diagram is clearly shown by the lesser number of cubes per unit volume of alloy—compare Figs. 58 and 28.

The strength of the alloys of group 1 was investigated in the same manner as described before. Fig. 59 shows the stress-deformation curves for the test samples taken from the lower portion of the ingots. The strength of the alloy increases from alloy No. 18 to alloys *a* and *b*, while further increase of lead content does not affect the strength of the metal. The same effect is demonstrated in a Brinell hardness chart in Fig. 60. The Brinell number increases with the addition of lead up to 1 per cent. After this point the hardness curve flattens out.

It is interesting to note that at elevated temperatures the effect of lead content gradually decreases, the effect at 125 deg. cent. becoming negligible.

The same characteristics of the effect of lead on the strength of a tin-copper-antimony alloy are evident from the hardness data obtained with the alloys of group 2, shown in Fig. 61.

These data accord with the observations of J. R. Freeman, Jr., and R. W. Woodward (loc. cit.), who tested a 3.5Cu-7.6Sb-88.9Sn alloy with admixtures of lead up to 5 per cent. It is the authors' opinion that, since the practice of tinning shells with solder prior to pouring the lining introduces a small amount of lead into it, the babbitt used should be as free from lead as is commercially reasonable.

## Influence of Impurities on Tin

In view of the known effect of lead upon the mechanical properties of these alloys it is of importance to consider the analysis of the tin which forms their basis. Straits tin, for example, is relatively free from lead; commercial tin—"99 per cent"—contains

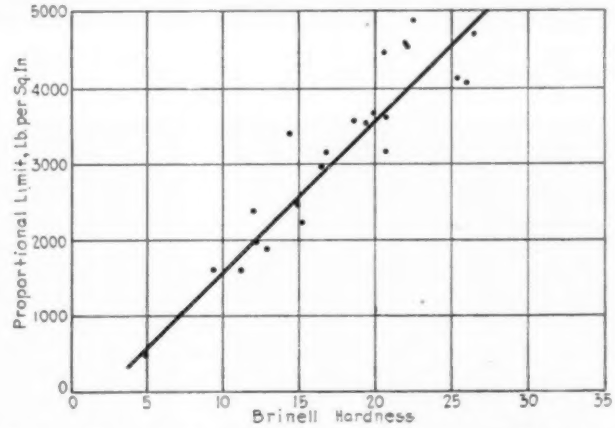


Fig. 53 Relation Between Proportional Limit and Hardness of Alloys at Room Temperature

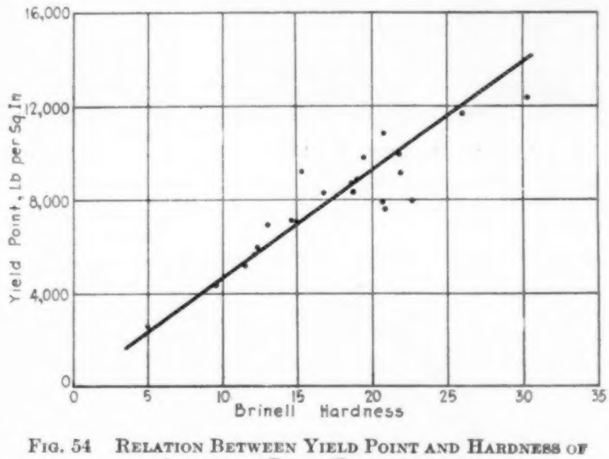


Fig. 54 Relation Between Yield Point and Hardness of Alloys at Room Temperature

up to about 1.0 per cent of lead. Typical analyses of these varieties are quoted below.

| | Straits | 99 per cent |
|---|---|---|
| Tin | 99.95 | 98.99 |
| Lead | 0.032 | 0.78 |
| Copper | 0.005 | 0.12 |
| Iron | 0.010 | 0.02 |
| Bismuth | 0.010 | 0.024 |
| Zinc | traces | traces |

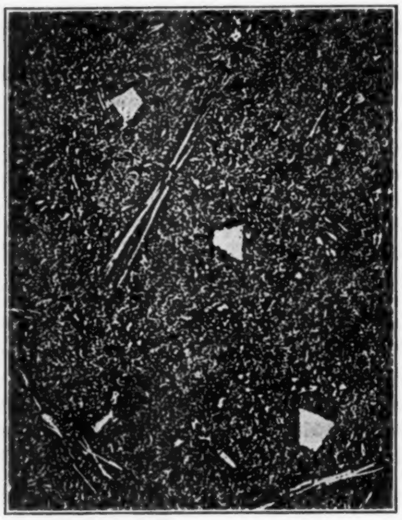

FIG. 55 ALLOY *b*, GROUP 1. 150X

FIG. 56 ALLOY *c*, GROUP 1. 150X

FIG. 57 ALLOY *a*, GROUP 2. 150X

FIG. 58 ALLOY *b*, GROUP 2. 150X

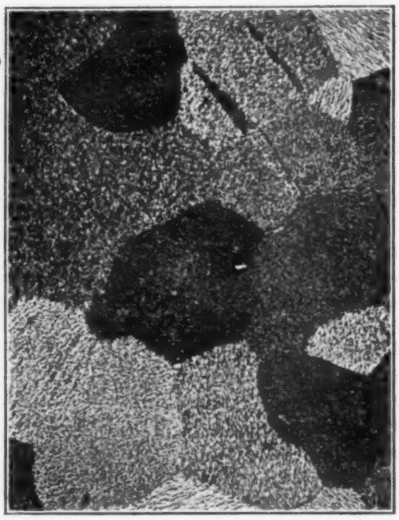

FIG. 62 STRAITS TIN. 250X

FIG. 63 99 PER CENT TIN. 100X

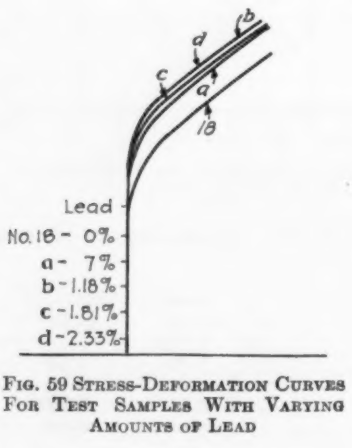


FIG. 59 STRESS-DEFORMATION CURVES FOR TEST SAMPLES WITH VARYING AMOUNTS OF LEAD

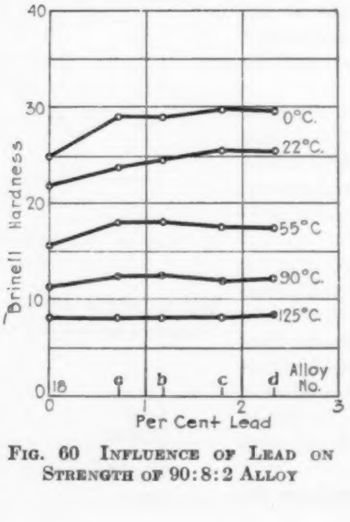


FIG. 60 INFLUENCE OF LEAD ON STRENGTH OF 90:8:2 ALLOY

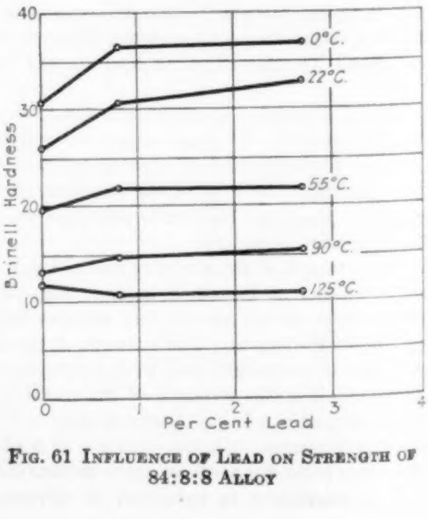


FIG. 61 INFLUENCE OF LEAD ON STRENGTH OF 84:8:8 ALLOY

The microstructure of samples taken from standard castings (mold in Fig. 3) made from these two brands of tin are shown in Figs. 62 and 63, which bring out the remarkable difference between the two materials in their reaction to similar treatments with the same etching reagent—undiluted ferric chloride. The white constituent which appears in Fig. 63 is doubtless CuSn.

The Brinell hardness of Straits tin was found to be 5.0, that of 99 per cent tin, 10.3.

Two alloys were made up of the same constituents and were cast under identical conditions. In one, Straits tin formed the base; in the other, 99 per cent tin; otherwise the alloys were exactly similar. No analyses were made, as the authors were interested only in comparing the properties of similar charges

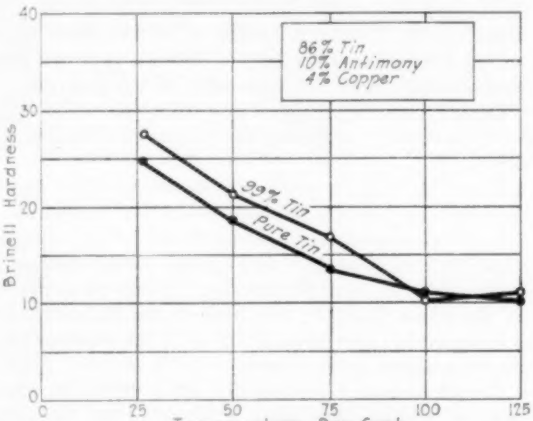


Fig. 64 Relation Between Temperature and Hardness for 86:10:4 Alloy Made With Tins of Different Analysis

with different basic metals. The results of hardness tests made at various temperatures on the castings obtained, which were of the following approximate analysis, tin, 86 per cent, antimony, 10 per cent, and copper, 4 per cent, are shown in Fig. 64.

### Conclusions

The authors have found that a systematic relationship exists between the mechanical properties of the tin-antimony-copper alloys of high tin content and their percentages of antimony and copper. The phase boundaries of the system were determined as a result of a complete metallographic study. A ternary diagram of the system is given.

A definite relationship has been shown to exist between the Brinell hardness numbers and the compression strengths of these alloys. The hardness numbers, therefore, satisfactorily express the mechanical properties of babbitts.

The strength of these alloys does not increase appreciably with antimony content above the point of appearance of the SnSb cubes. Addition of copper increases the strength of these alloys, but the rate of increase of strength falls off on the appearance of CuSn needles. This last effect is most pronounced when the alloys are tested at high temperatures. On this account it does not appear rational to use high copper contents in babbitts that are to work at temperatures in excess of 75 deg. cent.

Babbitts of high copper content must be poured at higher temperatures than those of low copper content, since the separation of CuSn on cooling occurs at rapidly increasing temperatures with increase in copper content.

The strength of these alloys falls off appreciably with increase in temperature within the working range of babbitts in bearings.

Lead has an important effect upon the microstructure of these alloys. It increases the mechanical strength of babbitts when added in quantities up to 1 per cent. Further additions have no strengthening effect whatever and at high temperatures this effect is entirely lost, no matter what the content of lead. The microstructural changes occasioned by lead tend to confirm the current opinions regarding its embrittling action.

## Discussion

R. L. Templin.[4] The writer does not believe that there is such a thing as zero Brinell hardness, either in theory or otherwise. There is, however, a minimum value that obtains when the diameter of the impression equals the diameter of the steel balls. This minimum value is a finite one, being 3.18 on the basis of using a 10-mm. diameter ball under a 500-kg. load. Therefore any curve that portends to show a relationship between Brinell hardness and tensile strength ought to take this fact into account in its equation as is usually done in an equation showing the relationship between the Brinell hardness and tensile strength of steel. Quite frequently the Brinell hardness can be multiplied by a constant to get an approximate value of the ultimate tensile strength of a metal, but strictly speaking this is not correct. For instance, the Brinell hardness multiplied by 550 gives an approximate tensile strength of most of the known wrought alloys of aluminum. More satisfactory results are obtained, however, f the known tensile strength of the material is divided by 550 in order to obtain a Brinell value of reasonable accuracy.

The authors state that in obtaining the Brinell hardness values the load was applied for thirty seconds. It has been found in the case of magnesium, for instance, that a satisfactory Brinell hardness value cannot be obtained unless the load is applied for an appreciably longer period, from $1^1/_2$ to 3 minutes.

A rule sometimes given for Brinell hardness test indicates that as long as the depth of the impression does not exceed one-third the thickness of the specimen, the thickness of the material will not affect the hardness. The writer, however, has not been able to check this rule in the case of the non-ferrous metals although he has performed the following experiment a number of times: A specimen of wrought aluminum alloy about one-half inch thick is first carefully given a Brinell test to check the uniformity of the material, then the specimen is planed off on one side so that it tapers from the full thickness at one end to a knife edge at the other end. Brinell hardness tests are then made on the unplaned surface at definite intervals until a point is reached where the readings become constant, that is, where the anvil effect or the specimen thickness ceases to change the hardness values. Our results show that if the depth of the impression does not exceed about one-thirtieth of the thickness of the specimen, the results are not affected by the thickness of the specimen.

With regard to the hardness tests on hard constituents existing in the form of large crystals in the material, we have found that in specimens containing large crystals as large as or larger than the Brinell ball used, so that it is possible to take readings on individual crystals, there seems to be very little difference in the Brinell values taken on the individual crystals or on the juncture of the crystals. This applies, of course, to aluminum alloys. We do find, however, in the case of Brinell tests of coarse crystal aggregates, as the Brinell ball is applied to the specimen, that certain of the crystals appear to rise up in the material while others are depressed adjacent to the Brinell impression. This causes the edge of the Brinell impression to be very irregular indeed and the determination of the Brinell hardness is quite doubtful. Another factor that should be considered is the differential recovery of cold-worked metal as the load is removed from the Brinell ball. In such cases the Brinell impression instead of

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being spherical in shape frequently has a four-sided appearance; then depending upon whether the diameters are read across the corners or across the sides of the impression, variations in Brinell values of from 17 to 20 per cent may be observed.

W. R. Webster.[5] In practically all of the copper alloys, the curve relating tensile strength to percentage of reduction by cold-working is fairly straight, having a slope which varies with specific alloys.

If a Brinell-hardness curve of the same series is drawn, it will start with a greater pitch angle, but will gradually flatten out until after a while there is very little increase in the Brinell, whereas tensile strength goes up all the time. It would be interesting to know if this has been observed in the alloys mentioned in the paper.

P. W. Brace.[6] In connection with the structure of each of these alloys, we have finally the duplex structure in which we find both the antimony-tin cubes and the needles and the cubes. The writer would appreciate information as to which type of structure seems to be best from the standpoint of bearing performance. Listening to various discussions on bearing metals, one hears many different ideas as to what is the best bearing metal. Each person who discusses the subject seems to have his pet alloy which will do a certain duty better than any other one.

Here we have mentioned three very definite types of structure, and some comment on the subject at this time seems desirable.

A. L. Davis.[7] In tests made by Scovill Mfg. Co., the Brinell test has seemed to be a good indication of the strength. It is much more convenient than laborious compression tests, and seems to be quite satisfactory.

In testing various bronzes and "high-lead" bearing metals, we have found much of interest, which in practice we have tried to follow out by using the various alloys for bearings under rolls. We recently found that we do not necessarily have to have an exceedingly hard metal to carry a heavy load, providing the speed is not too great. Some of the "high-lead" metals that are ninety-six or seven per cent lead, hardened up by sodium or alkaline earths, seem to be excellent. The only qualification is that under certain conditions they tend to pick up grit and act as a lap. When in such position that grit does not get in, they make admirable bearings under very heavy loads.

R. W. Cadman.[8] It has been found that the introduction of aluminum into tin-base babbitt has a tendency to break up the crystal and eliminate the antimony in tin and copper crystals. The elimination of crystals in white bearing metals seems to be the most essential thing we can strive for, because after all, the test of a babbitt metal is how long it will last without oil. Most any babbitt metal will carry the load so long as it has the proper lubrication, but with large crystals heat is sure to result, and heat is the source of the bearing's destruction. In the writer's judgment, the needle structure of the babbitt metal is the ideal condition. A metal is never harder than its matrix; therefore, the Brinell value may appear high when one or more of the hard crystals is encountered, but will drop if the test is made at another spot. While Brinell test is wonderful and keeps one informed as to the hardness of the metal, the writer does not believe that it is quite as important as the ability to carry load.

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[6] Research Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

[7] Research Engineer, Scovill Mfg. Co., Waterbury, Conn. Mem. A.S.M.E.

[8] A. W. Cadman Mfg. Co., Pittsburgh, Pa.

### Authors' Closure

In reply to Mr. Webster's inquiry as to the effect of cold work on the hardness and strength of these alloys it can be said that work in this connection is included in our program.

Mr. Davis' remarks are most interesting, since the authors are at the moment investigating the properties of typical high-lead alloys.

In reply to Mr. Brace's question as to the optimum structure for these alloys, we are not in a position at the present time to make any recommendation as to a specific alloy. It is necessary for further tests to be made before we can decide which of this system of alloy is the most satisfactory. Reference to the third page of the paper, however, will indicate the authors' present feeling in regard to those alloys which lie in the neighborhood of the phase boundaries of the system.

Mr. Templin's point regarding Fig. 52 is worthy of remark. However, on the previous page it is stated by the authors that there was no logical reason "to expect a definite correlation between compressive strength and Brinell hardness," the curve being of an empirical character.

As to the reliability of the hardness tests, one of the authors made a series of hardness tests some three to four months before the other. A comparison between the two sets of figures given in Table 2 shows that the results obtained by two observers at totally different times, using the same conditions of testing, are very close indeed.

With respect to Mr. Cadman's remarks, the authors believe that his criticism of the Brinell test is not justified. The longest cubes encountered in the alloys investigated by the authors were not more than $^1/_{300}$ in. across the edges. The size of the impression produced in the Brinell test of this same alloy (i.e., number 25), was about $^1/_5$ in. In other words the diameter of the impression was 60 times greater than the edge of the largest crystal.

In some instances tests were made on a baby Brinell machine, using a $^1/_{16}$ in. ball and a $7^1/_2$-kg. load. Even in this case it was found that the difference in the hardness at four different points in each sample was quite inappreciable.

It would be of great interest to the authors to have quantitative data in regard to the effects of small and large crystals on the antifrictional qualities of bearing metals. A search for such data forms, of course, a part of the authors' program.

MSP-50-12

# The Design and Building of Jigs and Fixtures

## A Brief Description of the Methods Employed by the Western Electric Company in the Manufacture of Telephone Apparatus and Equipment

By F. P. HUTCHISON,[1] KEARNY, N. J.

WITH the general adoption of tools which will insure interchangeability of product and the increasing necessity for more economical manufacture, the efficient designing and building of jigs and fixtures is being emphasized more than ever before as one of the important factors to be considered. One of the industries to which this statement may well be applied is that of manufacturing telephone apparatus and equipment, especially when handled on a large-production basis as is done in the plants of the Western Electric Company, where over 13,000 separate and distinct kinds of apparatus are manufactured, in the assembly of which are used approximately 110,000 different parts made on an interchangeable basis from over 18,000 different sizes, shapes, and kinds of raw material. The manufacture of this product involves not only all the standard operations usually found in wood- and metal-working shops, but many special operations as well. It requires the use of many different designs and kinds of tools falling under the general classification of jigs and fixtures ranging in cost from a few dollars to over $5000, and in size from drill jigs and fixtures which are small enough to be carried in a man's vest pocket, to portable fixtures used for assembling and holding during arc welding, structural-steel frames approximately 11 ft. long and 4 ft. wide. However, the larger proportion cost less than $400, as generally speaking the majority of the parts manufactured are small in size when compared with those used in engines, generators, heavy machinery, etc.

The same general procedure is followed for the manufacture of jigs and fixtures as for other classes of tools, the work being divided into five steps or divisions, namely, planning, designing, ordering, tool making, and inspection, which will be considered in the order given.

### Planning

In order to meet the increasing demands of the telephone business, new and changed designs of apparatus and equipment are constantly being developed for the purpose of improving the quality and reducing the cost of telephone service, which means that manufacturing requirements are continually changing. These new and changed designs must be analyzed and the best available methods of manufacture determined consistent with the quantity of parts to be made and the accuracy required. This work is performed by planning engineers, who prepare the manufacturing analysis giving the sequence of operations, tools and machines to be used, speeds, quantity of materials required for unit output, and other manufacturing information. These engineers determine the new or changed tools, such as jigs and fixtures, which will be needed, make a preliminary estimate of the cost, and prepare the necessary requisitions for their designing and building.

Studies are also being carried on by groups of engineers with the object of reducing manufacturing costs. As a result of these investigations requisitions are very often originated for the designing and building of new jigs or fixtures or for improvements in present tools. It would appear that if the planning job were done properly at the time of the original analysis, there would be no need for further study. However, this does not always hold true, as methods, processes, and tools which have already been proved and which it is known will work well, must be specified as far as possible in order that the product may be produced by a given date and at near the estimated cost. Later, after manufacture is under way, it is possible to try out new ideas and improved methods and tools without holding up production. Also in many cases the quantity of a part manufactured increases sufficiently to warrant improved and more expensive tools, which would not have been justified on the lower schedules.

After the tool requisitions have been written up and properly approved for expenditure in accordance with the estimated cost, they are routed to the Tool and Gage Design Division.

### Designing

The Tool and Gage Design Organization is divided into sections according to the class of work handled; for example, there is one group which designs drill jigs and tapping fixtures, another arc-welding, milling, and assembly fixtures, a third screw-machine and heading tools, a fourth riveting, molding, and spot-welding fixtures, etc. This plan is not only of advantage from an organization and assignment-of-work standpoint, but tends to produce more efficient designs and lower design costs, especially considering the very large variety of tools involved.

In order to handle efficiently between six and eight thousand requisitions a year, approximately one-third of which are for jigs and fixtures, it is necessary that the completion dates for the design work necessary be determined and the jobs scheduled accordingly on the groups handling each particular class of work. This function is performed by the scheduling section, who maintain a balanced load against each design section's capacity. The requisitions or orders are assigned to the designers by the supervisor in charge of the group. After the drawings have been completed they are checked in detail by checkers, and for general design by the section and department chiefs, before being finally approved by the chief of the Design Division.

The actual time and expense for design work are recorded for each order and included as part of the total cost of the tools. For jigs and fixtures the design expense may vary from 5 per cent of the total cost to several times this figure, depending on the nature of the design, amount of development work necessary, number of tools being built, etc. Every effort is being made through standardization and other means to hold design costs to the lowest possible figure consistent with good practice. Very few ink tracings are now being made at the time of designing except in special cases or where it is probable that the drawing will be subjected to considerable handling, as, for instance, when a number of prints may be required at frequent intervals for reorders or maintenance purposes. The majority of the drawings are made only in pencil on pencil-cloth cut to five specified sizes ranging from $7^1/_2$ in. $\times$ $12^1/_2$ in. to $31^1/_2$ in. $\times$ $38^1/_2$ in. within border lines, and with the standard form printed, so that no ruling or lettering for this part of the drawing is necessary by the designer. If it is later found advisable to make an ink tracing, this can be done when required. Meanwhile any corrections or changes found necessary in the design can be made

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Presented at a meeting of the Metropolitan Section of the A.S.M.E., Newark, N. J., March 28, 1928.

much easier and at less cost on the pencil drawing than if a tracing had to be changed. As between 1200 and 2000 drawings and sketches for jigs and fixtures are made yearly, there are now a large number of different designs on file, so that it is often possible to eliminate making a drawing for a new tool and specify that it shall be similar to another drawing with certain modifications. Where only one tool is to be made and the design is comparatively simple, instructions for making included on the order together with the drawing of the apparatus or piece part will often suffice. Approximately 12 per cent of the orders issued for new jigs and fixtures not previously designed are being handled satisfactorily on a not-drawn basis. In many cases a sketch or drawing showing only the drilling and milling layout and specifying standard parts is furnished.

Considerable progress has been made in the standardization of tool designs, and further studies of this nature are being carried on. Standard drawings have been made for various types of drill jigs and fixtures, as well as other tools, and details such as bushings, channels, latches, springs for plate jigs, gage pins, jig feet, clamping cams, etc. have been standardized and stocked where the quantities used are sufficient. Tool steels have been classified and assigned code numbers, except in the case of S.A.E. specification steels where the standard classification numbers are used. Trade names of steels are not shown on drawings except in special cases. The purposes for which the various steels are best suited have been determined by the Metallurgical Department, and a table with over 250 classifications of tools and parts has been prepared giving the code numbers of the proper steels to be used and the degree of hardness according to the Rockwell scale. S.A.E. 1020 steel is generally specified for jig and fixture parts made of machine steel, especially when case-hardened. Information is given on the drawing for each part as to the method, whether cyanide or pack hardening, and the specification number covering the process. In addition, if pack hardened, the depth of case, the treatment number, and the tempering temperature are shown.

A book of standard design practices has been compiled in loose-leaf form which is furnished each designer, and the following rules have been established in connection with its use:

1 The instructions and data included shall be followed as far as possible so that similarity will exist in the drawings made by different individuals, and designers are not to deviate from them without the consent of their supervisor.

2 Parts commonly known as standard tool parts, as well as such commercial articles as are kept in stock and ready for use, shall be incorporated in all designs whenever suitable whether the tool is new or to be changed.

3 Typical designs shown are to be followed as closely as possible whenever practical for the particular job on hand.

4 Economical production of equipment depends on the careful selection of parts and materials entering into the tool, and care should be taken to scan the data sheets as well as the stock lists for suitable parts and material before designing or using anything special.

Some of the important factors considered in designing drill jigs, and also tapping and milling fixtures where applicable, are:

1 Design of jig should be simple, light to handle, safe for the operator to use, and strong to withstand rough usage, so that accuracy is not destroyed.

2 Locating pins or blocks should where possible locate the part from the same points as in preceding operations, if any have been performed.

3 Clamps and methods of holding the work should be as few as possible consistent with rigidity and accuracy, and easy and quick to manipulate, so that loading and unloading time will be reduced to a minimum.

4 Provision should be made for chips and burrs so they can be easily cleaned out, particularly away from locating points.

5 Bushings should not be placed in movable parts, such as leaves, unless it is unavoidable.

6 The design should be such that all holes or as many as possible are drilled at one setting.

7 Wearing parts should be designed so that they may be repaired or replaced without reconstructing the entire jig or fixture.

8 Whenever possible and production requirements permit, the design should be such that a tool can be used for more than one part by means of interchangeable details.

Owing to the large variety of equipment and apparatus manufactured, many special designs of jigs and fixtures not required in the more or less standard or common manufacturing operations such as drilling, milling, tapping, etc. are necessary, which call for more than average designing ability. The assembly and adjustment of the apparatus require many different kinds of fixtures for locating and holding the piece parts in position in order to facilitate this work both on machines and by hand operations on the bench. Welding, both spot and arc, is an important operation requiring a large variety of fixtures, ranging in cost from less than $100 to several thousand dollars for the largest arc-welding fixtures previously referred to, which are used for welding dial-system frames made of channels, angles, and flat stock. These fixtures are mounted on trucks so that the details can be assembled by helpers and the fixtures moved into the welding booths for the welding operations. They must be designed so as to prevent distortion and maintain limits which are comparatively close for this class of work. Several of the drawings for these fixtures each cover as many as twenty-five large-size sheets. Many small parts are spot-welded in fixtures used in welding machines of the press type, and these are usually designed to assemble parts within close limits. In fact, in order to obtain the correct functioning of the apparatus or equipment and also to insure interchangeability in assembly, a large percentage of the piece parts must be made and put together with a considerable degree of accuracy, often within limits of less than 0.001 in. for some of the dimensions, and the tool designs must be made accordingly.

### Ordering

The Design Division forwards the tool requisition together with the necessary prints to the Tool Ordering Division. This organization checks the estimated cost and approvals, places orders for patterns, castings, or forgings, and standard commercial parts as required, and follows these orders to insure delivery to the tool room. They write up the final order giving the layout of the department to perform the work and operations to be performed by each, complete description of the tool, final estimated cost, and other manufacturing information. The order with prints attached is then forwarded to the shop with copies to the technical and accounting organizations interested.

### Toolmaking

Although in special cases and when production requirements have necessitated doing so, tools have been made in accordance with our drawings by tool manufacturers, the company has found it expedient and desirable as a general practice to build its own tools. Considering the high standards which are maintained and the accuracy usually required, a substantial advantage from both a quality and tool-service standpoint is gained by so doing. Approximately 600 toolmakers and machinists are normally employed in the actual making, changing, and repairing of tools, about 100 of whom are engaged on jig and fixture work. Specialization of work or division of labor in the toolroom has been

carried out to a high degree. The main groups are the milling-machine section, the grinding section, the lathe section, the gage, jig, and fixture bench-work section, and the punch-and-die bench-work section. These sections are further subdivided according to type of work handled, with specialists in each who do only that class of work, as, for example, there are men in the bench-work sections who work on the final fitting and assembly of drill jigs, others on assembly fixtures, etc.

When an order is received in the toolroom the necessary clerical work in connection with recording, scheduling, etc. is performed and the raw material and standard parts are drawn from stock. The material, including any forgings or castings, together with a work ticket is then routed to the proper sections for performing the various machining operations. The machined parts upon completion are forwarded for fitting to the bench-work section handling the particular class of work. Parts requiring hardening have this operation performed by specialists on this kind of work, using the most improved equipment and automatic temperature recording and control, after which they are returned to the bench-work section for the final fitting and assembly.

By this plan each operation is performed by a man skilled in that particular work, so that a minimum amount of time is necessary and increased efficiency and accuracy are obtained. Also since the skill required varies for the different operations, the proper grade of workman can be employed for each, thus resulting in a much lower labor cost than if a high-grade toolmaker, required for the bench work, performed all the operations and built the tool complete.

Practically all of the accurate work in connection with laying out and boring holes in jigs and fixtures is done on jig-boring machines and vertical millers equipped with verniers, and methods such as the size-block, disk, button, vernier caliper, height gage, etc. are seldom used. As in the case of other machine operations, this work is performed by specialists experienced on these machines, so that the highest quality and accuracy with the minimum amount of time required are obtained.

As previously mentioned, details such as drill bushings, latches, springs, gage pins, clamping cams, jig feet, etc. have been standardized and are made in quantities and stocked. In addition to jig and fixture details, parts for other types of tools and a large variety of small tools, including taps, dies, reamers, and milling cutters are made and handled on a stock basis. This work is performed by a separate toolmaking department set up for this purpose and a large part of it is done on a gang piece-work basis, the earnings being distributed weekly on a pro rata basis in a manner similar to regular production in the general manufacturing departments. Standard manufacturing layouts giving the operations to be performed, machines and tools used, etc. are issued for stock parts, the same as is done for apparatus and piece parts, although the amount of detail given on the layouts varies according to the nature and output requirements of the part. A plan such as this, which results in large economies, is of course practical only where the quantities to be made justify such a practice.

### Inspection

Upon completion, the jig or fixture is routed to the Tool Inspection Organization where it is inspected for workmanship, conformance with the drawing, and whether the part produced is satisfactory. In some cases it is necessary to make a test of the tool under operating conditions, commonly termed a "try out," in order to determine the accuracy, probable durability, safety, speed, ease of operation, and that it does not injure the product or disturb any previous adjustments. In this connection it might be mentioned that while the convenience of using the jig or fixture must not be overlooked as an item in facilitating production and preventing unnecessary fatigue, safety of the employee is a factor of paramount importance which is always given careful consideration.

Tool inspection in reality forms the connecting link between the manufacturing tools and the finished product. Good inspection requires not only the ability to interpret drawings and make accurate measurements, but some degree of technical knowledge as well and an appreciation of the economical and correct use of tools and gages. Tool-inspection work has also been developed and divided into more or less specialized units, with the resulting advantage of higher-grade work at less cost. To facilitate inspection operations and insure the required accuracy, precision measuring instruments and gages, such as Johanssen and Hoke gage blocks, dial indicator gages, optimeters, and contour-measuring projectors are used, although these are not required as much in connection with jigs and fixtures as for some of the other types of tools and gages made.

### Conclusion

To cover completely all the practices, methods, routine, etc. followed by the Western Electric Company in the design and building of the many different types of jigs and fixtures is beyond the scope of a short paper of this kind, and in the foregoing description an effort has been made merely to give, without the inclusion of too many details, a general picture of the way the work is handled. Although the present practices are satisfactorily meeting requirements at a reasonable cost, this does not necessarily mean that they are considered the best possible methods. As mentioned before, studies are being carried on and improvements and changes are constantly being made in an effort to further reduce costs and still maintain high standards of quality and accuracy.

MSP-50-13

# Maintenance of Machine Tools

## Procedure of the Singer Manufacturing Company in the Repair of Old Tools And the Purchase or Building of New Ones

By J. C. MATTERN,[1] ELIZABETHPORT, N. J.

IT IS THE author's purpose to describe the plan under which the firm he is employed by operates in the maintenance of its machine tools.

Maintenance of machine tools as treated in this paper will cover:

The repair of machine tools

The purchase of new machine tools

The building of new machine tools by the tool room or machine shop.

There is little room for discussion as to the final action in either the repair, building, or purchase of machine tools. When the decision has been reached, the obvious thing to do is to act. Where engineers will differ, however, is in regard to the procedure to employ. It will be well at this time to describe the various agencies that carry out the work of repairing, building, or purchasing of machine tools.

The mechanical-engineering department consists of a small body of men well trained in the machine requirements of the plant. Some of them in their activities cover the whole plant, while others confine themselves largely to certain departments. This department works with the designing department, or drafting room, as it is usually called.

Here again, while no hard-and-fast lines are drawn, each of the four chief designers specializes along certain lines in the design of special machine tools. It might be said in passing that the two organizations above described are quite flexible as regards the work they are at times called upon to do. A condition arises where the tools necessary to manufacture a new product are to be produced in the shortest possible time. Immediately practically all other work in process is stopped and both departments devote their entire time to the designing and drawing of the machines and tools needed. By so doing the work is soon put up to the tool room.

Working in conjunction with the mechanical-engineering and drafting departments is the central tool room, which is in reality a tool room as that term is generally understood, and also a machine shop. Its organization consists of a department manager, machine foremen, and assembly foremen.

These assembly or erecting foremen are men who are specialists in certain types of machines used in the manufacture of the company's product, and while as a rule they work on the machines in their line, nevertheless the same flexibility exists here as in the drafting room.

When the case arises where it is necessary to build the tools to manufacture a new product as quickly as it can possibly be done, these assembly foremen drop all work that can be sidetracked and build jigs, fixtures, or any type of machine tool needed.

The manufacturing plant is composed of many departments, each having its special line of parts to produce or assemble, and each department having its machine tools designed and built or purchased to produce its work at as low a cost as possible consistent with maintaining the high quality demanded by a heartless inspection department which is armed with as good a line of gages as the mind of man can devise.

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Presented at a meeting of the Philadelphia Section of the A.S.M.E., Philadelphia, Pa., November 22, 1927.

The department organization consists of department manager, equipment man, tool-room foremen, section foremen, and cutter setters. There are other members of the department family, but they have little if any relation to the subject of this paper.

### Repairing Machines

When to repair a machine rests mostly with the section foreman, the reason being that he is most directly responsible for production running parallel with the orders, and for the quality of the product turned out. All of his work is subject to rigid inspection, bad work being of course rejected, and a record of such "spoilt work" being kept by the cost department. In addition a loss percentage is set, above which he must not go.

Beyond the section foreman the equipment and department managers are also responsible for "spoilt work." These three men are therefore keenly interested in having their machine-tool equipment in good condition. Being responsible for production as well as quality, they are in the best position to determine when a machine should be repaired. They look into the stock on hand, determine how long the machine can be shut down, and ascertain whether they have another machine capable of doing the work in the department that can be substituted. In short, they review the situation as it affects this machine.

We have here keen personal interest—personal responsibility resting on men who understand the work to be performed, who are intimately acquainted with the machine that does the work. If they fail, this will be shown by either the quality or the cost of production. There is no central authority that keeps a record of the 15,000 or more machine tools in the plant as regards the number of times a machine is repaired and at what cost it was repaired. The exception to this is where a machine fails to stand up as it should and is constantly developing trouble, and when such is the case, the bookkeeper of the department in which the machine is located starts a record card showing the time and cost of each repair job. The case of this machine is taken up by either the department manager or equipment man with the mechanical-engineering department, who take means to correct the trouble by changing the design, substituting another machine or any action which in their judgment is best. But no action is taken without consulting the department organization.

It is within the scope of a member of the mechanical-engineering department to call to the attention of the department manager the condition of a machine and advise that it be repaired.

A decision having been reached by the department manager that a machine is to be repaired, an order is issued either on the department tool room or the central tool room, and this brings up the question of how and where the work is to be done.

If it is a minor repair the order is placed with the department tool room and none but the department organization, as a rule, takes any interest therein.

If the repair work is of any magnitude, or must be very quickly accomplished, it is sent to the central tool room where the department manager assigns it to the assembly foreman who specializes in that type of machine tool. If a machine of the type to be repaired can be purchased, the tool room estimates the amount of money necessary to cover the cost of repairing the old machine. The matter is then analyzed by the mechanical-engineering department and the manager of the department interested. If

the decision is to buy a new machine, a report is drawn up setting forth the facts in the case and asking for an appropriation of a sum necessary to purchase the new machine.

The cost of the new machine having in the meantime been obtained through the purchasing department on quotation, this report is submitted to the works manager for his approval. Action in accordance with his ruling is then taken.

One other phase of the question should be mentioned at this time, namely, that of improving the machine to be repaired as a means of reducing the cost of the part it produces. A suggestion to this end can emanate from the superintendent of works, the department owning the machine, or the mechanical-engineering department after the proposed improvement has been discussed by the organizations interested and approved by the head of the mechanical-engineering department and department manager; and if deemed of sufficient importance submitted to the superintendent and works manager, and if by them approved, the machine is rebuilt.

The reason for making the repairs in the central tool room as against doing the work in a special repair shop is that there are in the central tool room foremen who are in fact experts on the many different types of machines used to produce the plant's product, and a better result is obtained than would be in a repair shop where it would be impossible for the foreman and men who do the work to have the same degree of knowledge and experience.

### Purchasing or Building New Machines

New machines are installed for the following reasons:

*a* When an old machine has reached the point where it should be replaced by a new one

*b* When a new machine can be built or purchased and the saving in cost of production of the part or parts produced thereby will defray the cost of the new machine within a period of from three to four years

*c* When their purchase or construction is necessary because of an increase in production or a new product added to the line

*d* When in the cost of machines purchased for the tool department the estimated saving on work will pay for them within four years.

No old machine is scraped, no matter what its age, unless the new machine that would replace it can prove itself by showing a worth-while reduction in the manufacturing cost of the part produced.

The author can call to mind machines probably from 30 to 35 years old, performing simple drilling operations, located in a line where the operator serves a number of machines, and where the machine cost is such that no new machine up to this time has been thought of that would reduce the cost at all.

The suggestion to build or purchase a new machine having for its object the reduction of the cost of manufacture of a part or parts can emanate from any source whatsoever. The works manager or the superintendent may order an analysis because of the facts shown by the cost sheets. The department manager, section foreman, department equipment man, any workman if he has an idea, any member of the mechanical-engineering or drafting departments, is listened to and encouraged to make suggestions.

With very few exceptions all suggestions either to build or to purchase new machines ultimately come to the mechanical-engineering department, where the cost of the new machine is compared with the estimated saving in the production cost of the part or parts to be machined.

If the estimated saving over a period of three or four years equals the cost of the new machine the facts are entered on a form sheet designed for that purpose, setting forth the operations and prices paid therefor in one column. Another column shows the operations as it is proposed to perform them on the new machine and the price to be paid. A third column sets forth the saving in cost to be made, and a fourth either the amount of money needed to design and build the new machine or, if bought outside, the purchase price. At the bottom of the sheet is shown the length of time necessary to pay for the new machine. As mentioned before, the period set is from three to four years, provided no element except cost reduction is considered. Should it be a matter of safety, a machine may be altered, or a new one built or purchased, without the necessity of showing a reduction in cost of manufacture.

Where new machine tools are required for a new product added to the line, the following action is taken.

The new parts are assigned to the various departments by certain men of the organization. The operation lists are then written up by men trained in this procedure, who work closely with the department organization on the parts assigned to them. The author would like to emphasize the desirability of close co-operation between the department organization and the machanical-engineering department, the drafting department, and the central tool room, both in the designing and building and in the purchasing of new machine tools.

Upon completion of the operation sheets the mechanical-engineering department in conjunction with the drafting department and department organization maps out the types of machines to be built or purchased and settles on their cost. All of this is then submitted for approval to the works manager and superintendent of the works. If approved, usually a due date is given, and the work is assigned.

The central tool room does its own repairing when and how it pleases.

The purchase of new machine tools for the central tool room is also based on the ability of the contemplated new tool to show such an increase of work turned out over the old tool that it will pay for itself within the given three or four years. The reduction in cost is arrived at in the following manner. Drawings of from 10 to 12 jobs or samples of work to be done are sent to a firm building the machine tool under consideration, for time studies on the drawings or samples submitted. These time studies are checked against the best that can be done on the machine tool or tools to be supplanted.

There is considerable ground for discussion in this work of maintaining the machine tools of a manufacturing plant. Among many, the following questions are those that most frequently present themselves to the author:

Is the rule that a new machine must pay for itself in from three to four years all that is necessary? Should elements other than the element of safety of the operator enter in?

Should there be a central organization with records and an office force to keep track of the machines in use instead of leaving matters with that part of the organization that is directly in touch with the machines? Are there certain vital elements entering into the question that these men know nothing about?

Is it best to have a repair shop where all repairs are made and should this shop handle nothing but repairs?

MSP-50-14

# Maintenance in the Large Industrial Plant

## Details of System Employed in the Henry Disston & Sons Works, With Maintenance Costs Of Machinery Expressed as Percentages of Productive Labor and As Percentages of Book Value

By C. M. Thompson,[1] Philadelphia, Pa.

There are two systems of maintenance of property and equipment in an industrial plant. One is to allow machinery to run until a breakdown occurs and then order repairs, while the other system is based on periodic inspections and minor repairs in an attempt to forestall interruptions to production.

Which of these systems should be used is a matter to be decided by the management of the individual concern, but there are, however, certain pertinent factors which should be considered: namely,

1 Size of plant
2 General layout
3 Product manufactured
4 Source of power supply, and
5 Labor conditions.

Before discussing the subject in detail, it might be well briefly to outline the influence the above items exercise on the problem in which the author is particularly interested.

The plant of Henry Disston & Sons covers approximately 63 acres and contains 54 buildings with a total floor space, excluding the steel works, of about 530,000 sq. ft. (more than twice the area of the main span of the Delaware River Bridge), requiring a larger force than would be the case if the various departments were confined in a fewer number of buildings.

There are three main divisions in the factory, namely, steel works, saw works, and file works, each presenting varied maintenance problems. The saw and file works buildings are of the slow-burning mill-type construction of one and two stories, while those in the steel works are of typical steel-mill construction.

An idea of the many types of machinery installed in this plant can be gained from the following partial list of products manufactured: Steel, saws, files, knives, trowels, shears, squares, levels, screwdrivers, scrapers, as well as a large number of metal products, such as automobile clutch disks, etc.

The power supply at the present time is largely electric, although seven rolling mills in the steel works and three departments in the saw works are driven by reciprocating engines which are supplied from two stoker-fed boiler plants. There is a considerable amount of process steam used, the majority of which is for dry kilns and steam boxes in the lumber yard. The exhaust steam from the rolling-mill engines is delivered to the power house where three low-pressure turbo-generators supply about fifty per cent of the electric-power load. The remainder is supplied by the Philadelphia Electric Company.

Being situated in an industrial center such as Philadelphia, a plentiful supply of skilled labor is available at reasonable wages, which permits the employment of first-class mechanics in their respective trades. This is especially true in the Maintenance Department.

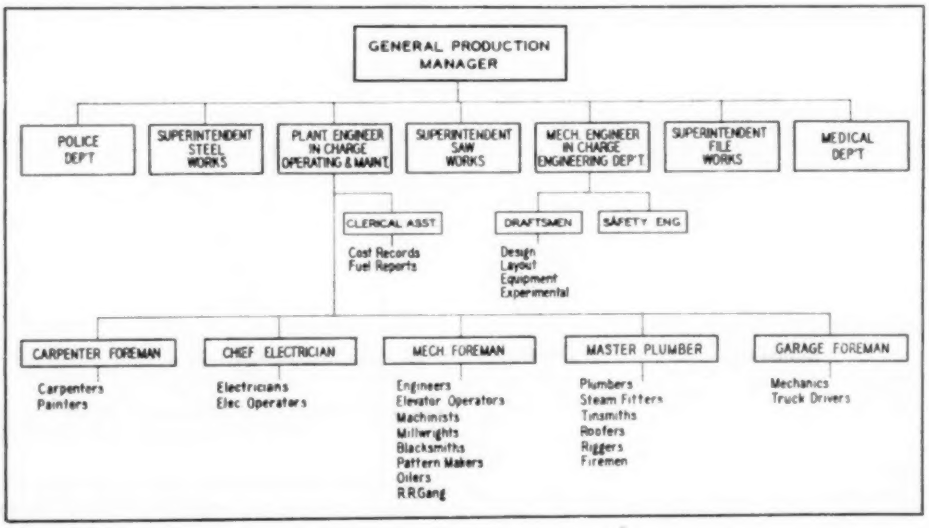


Fig. 1 Organization Chart Showing Various Divisions of Maintenance Department, Their Respective Duties, and Relation of Whole to Production and Engineering Departments

Fig. 1 is an organization chart showing the various divisions of the Maintenance Department, their respective duties, and the relation of the whole to the Production and Engineering Departments.

As customary, the Maintenance Department is responsible for the upkeep of buildings, grounds, equipment, and machinery and in addition the operation of the power supply. The department consists of a plant engineer in charge, an assistant whose duty is the supervision of the clerical work, such as costs, records, fuel reports, etc., and five subdivisions as shown in the organization chart.

The Mechanical Division is responsible for the upkeep of all

[1] Plant Engineer, Henry Disston & Sons, Inc.

Presented at a meeting of the Philadelphia Section of the A.S.M.E., Philadelphia, Pa., November 27, 1927.

engines, lineshafting and main drive belts; elevators; railroad tracks and roads, cranes, etc. All engines are thoroughly inspected, including removal of cylinder heads, twice a year. An oiler is employed to care for all main lineshaft bearings and report any trouble with either shafting or belting. The oiling of machinery and countershafts is the responsibility of the individual departments. Weekly inspections of all cranes are made and reported on a special form shown in Fig. 2.

The Electrical Division's duties comprise the upkeep of all

CRANE INSPECTION

MAKE........CAPACITY........TONS. LOCATION.........DATE

INSPECTOR.........................

CONTROLLERS:
- Contacts
- Fingers
- Wiring

SHAFTING:
- *Bearings
- *Gears
- *Brake
- *Grease

LIMIT SWITCHES:
- Mechanism
- Wiring
- Fuses

SWITCHBOARD:
- Circuit Breakers
- Knife Switches
- Shunt Trip Coils

MOTORS: *Bridge* *Trolley* *Large Hoist* *Small Hoist*
- Slip Rings
- Brushes
- Brush Holders
- Wiring
- Mag. Brakes
- Bearings
- Oiling
- *Pinions

HOIST BLOCKS: *Large Hoist* *Small Hoist*
- *Bearings
- *Sheave Wheels
- *Oil or Grease
- *Hook
- *Swivel
- *Cable

DRUMS:
- *Bearings
- *Oil or Grease
- *Gears

BUSES: *Runway* *Bridge*
- Wires
- Insulators
- Supports
- Wheels
- Wheel Arms

TRACK:
- *Rails
- *Clamps
- *Plates

WHEELS: *Bridges* *Trolley*
- *Axles
- *Journals
- *Gears
- *Wheels
- *Grease

GENERAL CONDITIONS

NOTE: * Indicates items covered by mechanical inspection.

FIG. 2 FORM FOR USE IN CRANE INSPECTION

electrical units, including the oiling and cleaning of all motors and generators, weekly inspection of cranes and the melting furnaces, and a daily inspection of the substation equipment and all large motors. The electrical inspector also changes all charts and collects them from the recording instruments. In addition to the large units, there are about 425 motors in operation, ranging in size from 1 to 75 hp. Two electricians are assigned to the cleaning of motors each week end, and by this procedure it takes about 5 months to complete a round. Every other Saturday the entire electrical force is assigned to the oiling of motors, each man having a specified group, thereby completing the job in about four hours. By this means the maintenance expense of motors is held to a minimum, as any apparent trouble such as bearing, loose pulleys, etc., is noticed before a shutdown is necessary. The total cost of oiling, cleaning, and repairing the entire motor installation averages $1.60 per hp. per year. Card records are kept of the data of each motor and its location, together with a complete record of the dates the motor was cleaned and any repairs made.

The cleaning and replacing of electric lamps is also the duty of this division. Lamps are cleaned about every six weeks, requiring one man's time for about two weeks to cover the factory. The cost of this cleaning amounts to about $400 per year. The replacement of defective or blown fuses is prohibited except by an electrician, thereby bringing to this division's attention any trouble, such as overload, grounds, etc., in order that corrective measures may be taken immediately.

It has not been the practice of the management to budget repairs. Records are kept of repair costs, however, and are given to the superintendent of each department every month. All maintenance orders are returned, when completed, to the

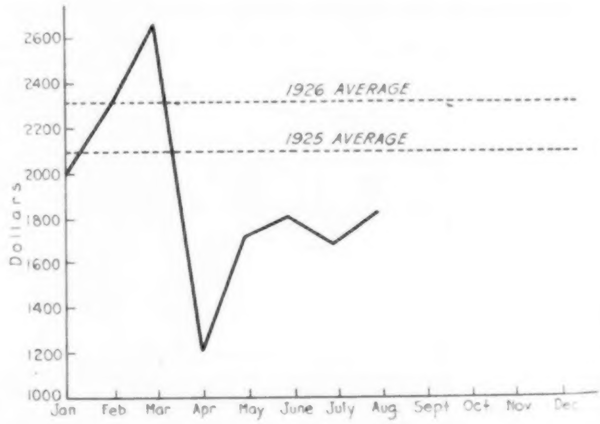


FIG. 3 MACHINE-SHOP OPERATING COSTS FOR 1927 AS COMPARED WITH AVERAGES FOR 1925 AND 1926

department requesting the work to be done, showing the amount of labor and material expended so that the superintendent has the opportunity to check the job and enter complaint if he believes it justified. In the saw works the superintendents of the various departments meet once a month, at which time the operating costs are presented. The details of these figures, such as non-productive labor, tools, supplies, and repairs are discussed and comparisons made with previous months on the basis of the billing value of the finished product in order that each superintendent may be familiar with the trend in his respective department.

Three years ago the author started giving each division head in the Maintenance Department the cost figures over which he had direct control, and also a chart showing the total expense charged against his division. These charts include depreciation, taxes, insurance, etc., in addition to the direct charges. Fig. 3 is the expense chart for this year for the Mechanical Division and when compared with the averages of the last two years gives a very good idea of what can be accomplished. The machine shop of this division not only handles maintenance jobs, but also the building of new machines and some production work.

There are 143 men employed in the maintenance and operating groups. This force is made up of the following:

| | | |
|---|---|---|
| 29 Machinists | 12 Engineers | 9 Electricians |
| 6 Tool makers | 8 Elevators operators | 9 Carpenters |
| 2 Millwrights | 20 Firemen | 4 Painters |
| 7 Blacksmiths | 2 Electrical operators | 2 Plumbers |
| 2 Pattern Makers | 6 Truck drivers | 7 Steam fitters |
| 2 Iron workers | 2 Auto mechanics | 2 Tinsmiths |
| 2 Roofers | 1 Oiler | 2 Riggers |
| | 7 Laborers | |

In order to compare maintenance costs of machinery the usual practice is to base it on a percentage of productive labor. Productive labor is a definite quantity, and the executive wants to know how much of every dollar of productive labor is spent for repairs. These figures for the saw works, by departments, are as follows:

| Department | Percentage of productive labor |
|---|---|
| Maintanance (Planers, shapers, lathes, drill presses, and milling machines) | 0.4 |
| Saw Tool (Lathes, shapers and milling machines) | 0.6 |
| Handle (Woodworking machines) | 0.7 |
| Hand Saw (Shears, presses, grinders) | 1.7 |
| Long Saw (Shears, presses, grinders) | 1.8 |
| Drop Shop (Hammers) | 1.9 |
| Milling Saw (Gear cutters) | 2.9 |
| Circular Saw (Shears, presses, large grinders) | 3.4 |
| Band Saw (Shears, presses, large grinders) | 3.5 |
| Jobbing (Shears, presses, lathes, large grinders, and furnaces | 6.3 |
| Hardening (Furnaces) | 8.0 |

From these figures it will be noted that, in departments where the costs are very nearly alike, the class of machinery is similar.

In order to give some insight into the maintenance costs of machinery by classes it may be of interest to compare them on the basis of percentage of value. The percentage for the machinery in the Saw Works on the basis of present book value is as follows:

| | | Percentage of book value |
|---|---|---|
| Group I | Planers, Milling machines, Shapers and slotters, Lathes, Drill presses, Gear cutters, Boring mills, Screw machines | 0.5 to 1.0 |
| Group II | Buffers and polishers, Filing machines, Small grinders, Woodworking machines, Drop hammers | 1.5 to 3.0 |
| Group III | Shears, Punch presses, Large grinders | 4.0 to 5.0 |
| Group IV | Heat-treating furnaces | 8 |

The figures given in these tables may not check with those in similar industries but they give some idea of what may be expected in an industrial plant having as widely varying activities.

# Inspection Methods and Quality Control in the Manufacture of Aircraft-Engine Parts

By HUGH W. ROUGHLEY,[1] PATERSON, N. J.

THERE was a time not so many years ago when the inspection department in a manufacturing organization was considered a good talking point and a novelty to show to visitors going through the factory; aside from that, it was considered one more item of overhead expense. Within the last decade, however, manufacturers carrying on quantity production have recognized the importance of efficient inspection throughout all processes of fabrication and assembly. The purchasing department must have assurance that raw material is in accordance with purchase order and specification requirements; manufacturing-department costs must be held down to a minimum by the rejection of defective parts in the early operations rather than permitting a part to be completely finished only to be rejected at final assembly; and, most important of all, the engineering department must know that each part going into the finished product is in accordance with blueprint dimensions and material specifications.

In the manufacture of Wright aircraft engines, inspection is of paramount importance. From the time the raw material enters the factory until the finished engine is finally tested and packed for shipment, all raw material and every operation in the process of manufacture is subjected to the exacting scrutiny of a large force of specialists, men adequately trained to carry on the exact inspection found necessary through long experience in the manufacture of reliable aircraft engines.

## Inspection of Raw Material

Going into detail we shall first take up inspection methods covering raw material. Bar stock, forgings, castings, etc., which will meet chemical and physical requirements and at the same time be free from seams, cracks, laps, blow-holes and mis-runs, are carefully inspected upon receipt. All purchased material is delivered to the inspection department, accompanied by receiving reports identifying the material as to size, specification, and quantity. After checking material for quantity, size, and certified chemical properties against the purchase order, it is then checked against the bill of material and also against the drawing to insure its conformance with engineering requirements.

In the case of bar stock, if purchased heat-treated, 100 per cent hardness test is made on both ends of each bar on either a Brinell or Rockwell testing machine. Tensile tests pieces are made on each lot of material and tested to insure physical properties called for in the drawing or specification. Bars are carefully inspected for seams and cracks, any bars showing imperfections being rejected. Each accepted bar is stamped with specification number and lot number on each end in order to positively identify material from the raw state to the finished product. An exact record is entered in the metallurgical log book, giving specification number, lot number, heat number, amount of material received, amount of material accepted, amount of material rejected, and name of vendor.

In addition to stamping specification number and lot number, each bar is painted its entire length with the color combination designated for its particular material specification. This furnishes a convenient method of identification in the stock room and through the manufacturing departments so that the identification of material which is not up to requirements is possible at any stage of production, from raw material to finished product. For instance, twenty-three different grades of steel are purchased for various parts of Wright engines—tough steel of low carbon content to be case-hardened for piston pins, knuckle pins, and gears; high-speed tool steels, tungsten and cobalt chrome for exhaust valves and guides; high-carbon chrome nickel and high-carbon vanadium steels for highly stressed parts such as connecting rods, studs, bolts, and nuts; carbon steel for washers, keys, pipe flanges, etc.—most of which is received in long bars of identical appearance, so far as quality is concerned. It is evident, therefore, that positive identification of material is of the utmost importance.

## Inspection of Forgings

Inspection of forgings is carried out along lines similar to inspection of bar stock. Extraordinary care is given to the inspection of crankshaft, connecting-rod, and rocker-arm forgings, inasmuch as they are subjected to extremely high stresses.

In order to meet the exacting engineering specifications for crankshaft forgings it is necessary to have the steel manufacturers make special heats. After the heat has been poured, several chemical analyses and a number of metallographic examinations from different sections of the ingot are made, after which those acceptable are cropped at each end, using only 50 per cent or the center portion. This is done in order that only steel of the highest quality, free from slag, pipes, and non-metallic inclusions, will enter into forgings for crankshafts.

At the forge shops inspection again plays its part. The first shaft off the dies is sectioned through its center line and deep-etched in 50 per cent hot hydrochloric solution to show structure. The flow-lines in the shaft are then studied by the metallurgical department and, if approved by the chief metallurgist, the forge ship is permitted to proceed with the order. To produce crankshafts to meet these exacting requirements, expensive breakdown and edging dies are required in addition to finish-forging dies.

After heat treatment, each forging is given a serial number and is brinelled on each end and in each cheek. If the hardness is uniform, tensile and impact tests are made from each end of the shaft and portions of the impact specimens are polished and carefully examined under a high-powered microscope in order to determine that shaft has been properly heat-treated. A photomicrograph is then made and filed with the record of each individual shaft which already contains the heat number of the steel used, the chemical analysis of the heat, and the physical properties, thus giving a complete history of each shaft. After shafts are completely machined they are again brinelled on each cheek in order to insure that proper heat-treatment penetration has been accomplished. After final inspection for dimensions, shafts are again carefully inspected with a magnifying glass and high-powered binoculars.

A careful record is kept on file in the inspection-department office showing the engine number, the serial number of the crankshaft installed therein, and the complete history of the shaft from the time it was forged, including part number, heat treatment received, and final physical properties obtained at the time the

[1] Quality Manager, Wright Aeronautical Corporation.

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specimens of the particular shaft were tested at the forge shop.

Steel for connecting rods has the same requirements as that for crankshafts and the rods are given the same inspection at the forge shop, being carefully examined for imperfections. Upon receipt at our factory each connecting-rod forging is given a serial number in order that it may be identified as to heat of steel used in its fabrication, vendor supplying the steel, and vendor making the forging.

Connecting-rod forgings are rough-machined, heat-treated,

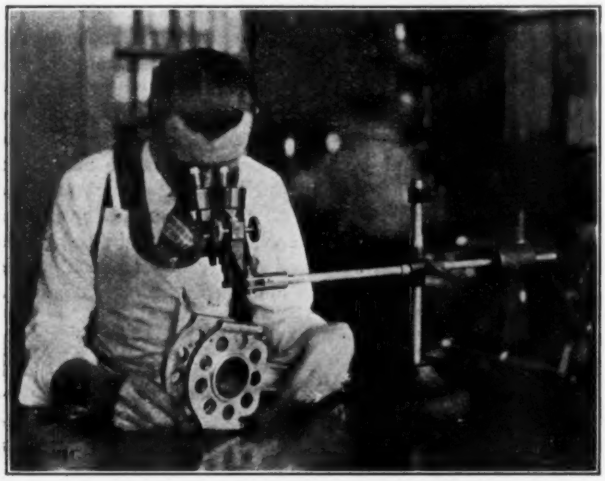

Fig. 1 Examining Finished Master Rod With 32-Power Binoculars

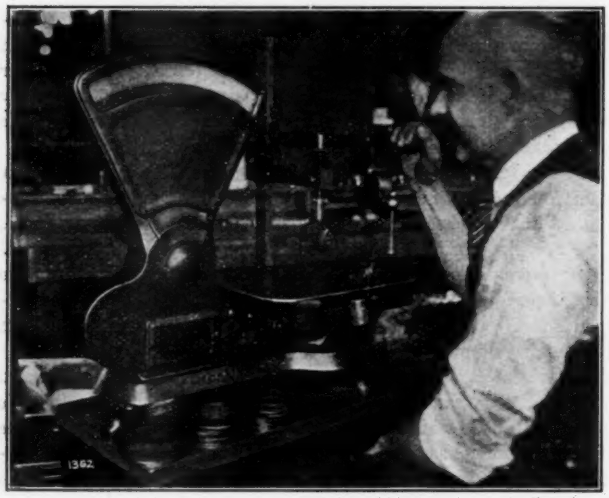


Fig. 3 Testing Piston Rings for Tension

and again carefully inspected for any small seams which did not show up previously. Physical tests are then made as follows: The rods are carefully brinelled and if within the hardness limits, one tensile specimen and one double-notch izod impact test specimen are made for each five treated. In ordinary commercial practice, only one tensile test is made for each furnace charge, which usually comprises in the neighborhood of 150 rods. After rods are completely machined and polished, they are given a final inspection for small imperfections under a strong magnifying glass and a high-powered microscope. (See Fig. 1.) At the same time a final check for hardness is made in order to eliminate the possibility of incorporating an unheat-treated rod in an engine.

Rocker-arm forgings are ground to remove flash and rough-finished all over. They are then heat-treated and all of the scale and surface imperfections of any nature are removed by scratch-brushing and sand-blasting. This is a very difficult operation to perform, owing to the fact that the rocker is of the I-beam-section type. Rockers are then carefully inspected for any imperfections and given a 100 per cent hardness test before being finish-machined and finally inspected for imperfections on the finished surfaces.


Fig. 2 Checking Free Height and Solid Height on Spring-Weighing Machine

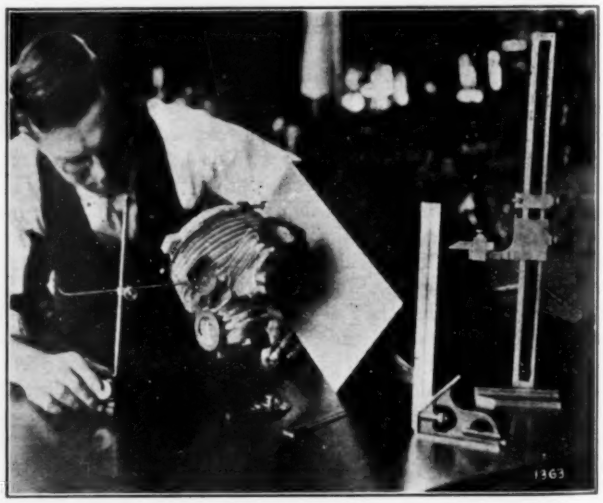


Fig. 4 Laying Out Cylinder-Head Casting to Insure Boss Diameters and Wall Thickness Meet Drawing Dimensions

### Inspection and Manufacture of Small Parts

Piston-pin stock is rough turned on the outside diameter, bored out, cut off, heat-treated, sand-blasted, checked for hardness, and examined for seams. After pins are finished ground they are lapped to a high-grade finish on a production lapping machine.

Numerous small parts having a hardness above 350 Brinell are machined from annealed bar stock, then heat-treated, and finally given a 100 per cent test for hardness, a representative number of tests being made to insure proper heat treatment. This procedure applies alike to gears, push-rod ball ends, washers, special studs, etc.

Connecting-rod bolts are classified along with crankshafts and connecting rods and are made of steel with identical specifications, requiring tensile and impact testing. In order to be sure that the material for these bolts is free from the slightest imperfection, the bolts are machined to within $^1/_{32}$-in. of finished size and inspected under a microscope.

In order to conserve production facilities, some parts are purchased completely finished. This practice also gives us the advantage of the vendor's years of specialization on a certain product. All parts purchased, however, are manufactured by the vendor to our specifications and are carefully checked against blue-print and specification upon receipt.

Valve springs, which ordinarily appear to be of secondary consideration, receive a careful inspection as to diameter of wire and careful check for spring load at proper compression height and also at solid height. In order to make accurate check of this, it was necessary to build a special spring-weighing machine. (Fig. 2.)

Piston rings might also appear of relative unimportance as long as their width and diameter check with the blueprint. As a matter of fact, however, the piston ring is one of the most important internal parts of an aircraft engine. Rings must be perfectly round and have at least 95 per cent bearing against the cylinder wall when installed on a piston assembly. To test this condition, a specially constructed light testing gage is used which should show contact throughout the entire circumference. The wall pressure is also of major importance and in order to check this condition accurately, it was necessary to provide an attachment to be used in connection with a sensitive scale. (Fig. 3.) All piston rings are inspected 100 per cent for dimensions,

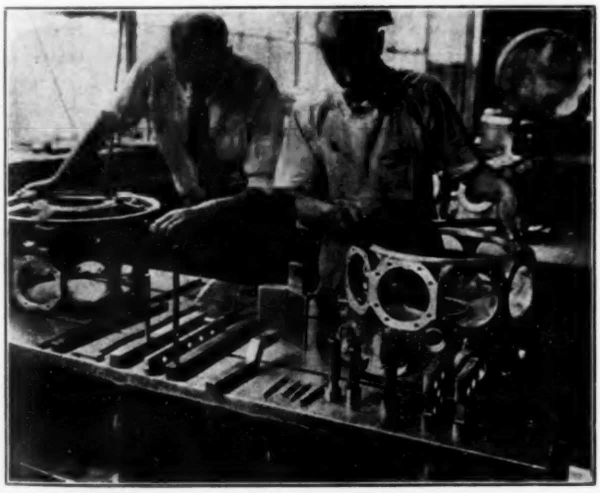

Fig. 5 100 Per Cent Final Inspection After All Machining Operations and Enameling Before Main Crankcase Is Delivered to Finished Stores
(Note gages required for rapid inspection.)

weighed for wall tension, which should range from 8 to 11 lb., and tested in a light gage to insure perfect bearing against cylinder walls. Rings failing to meet any of the above requirements are rejected.

### Inspection of Castings

Rigid inspection of castings is of utmost importance in maintaining standards of quality. Nine different aluminum alloys and eight different bronze alloys are used and a careful inspection of castings is inaugurated immediately after the castings are knocked from the molds. Each casting and each test bar is stamped with its heat number in order that identification of material may be positively established. The inspector then fills out the log sheet for the particular heat, showing the heat number, the different elements going to make up the charge for a particular alloy, the furnace temperature, the pouring temperature, the part number of each piece, the number of pieces poured, and the number of pieces accepted on preliminary inspection.

Of the nine different aluminum alloys used, seven are tested for physical properties in the condition as cast and tensile tests

Fig. 6 Corner of One of the Final-Inspection Cribs

are made each day for each alloy, representing a single day's production. The two other aluminum alloys, which are used in casting crankcases and cylinder heads, require heat treatment in order to obtain maximum physical properties. All heat-treated castings are stamped with heat number of the melt and lot number representing the particular heat treatment. In this way any castings which fail on test to meet the physical requirements can be properly identified for rejection.

After being thoroughly cleaned and sand-blasted, castings are given a final inspection and all cylinder heads, pistons, crankcase rear sections, and manifolds are pressure tested in order to insure sound castings and then very carefully inspected for mis-runs, shrinkage cracks, and "coldshots."

It is of the utmost importance that periodic layout inspections be made on all castings in production. Even though many of the patterns are of metal construction throughout, the periodic layout inspection is carried out in order to insure uniform wall thickness and conformance with drawings. (Fig. 4.)

### Inspection During Manufacture

Throughout the manufacture of the various parts, a large force of floor inspectors is required in order that each piece may be checked by an inspector who is familiar with that particular operation before an operator is allowed to proceed with the remainder of the order. In addition to this, the floor inspector floating among the various machines in his department checks pieces from time to time to see that quality standards on the particular part are maintained. Before a particular order for a certain operation is allowed to be moved to the next department for the succeeding operation, the inspector signs the back of the work order to show that he has checked the first piece and, in addition, has fair assurance the greater percentage of the work is in accordance with the quality standards set for that particular part.

Any parts found defective on floor inspection are rejected and delivered to the salvage department, the number of parts so rejected being deducted from the order. Floor inspectors are also on the lookout for seams, blow-holes, or flaws of the most minute character and if it is found that a large percentage of the parts are in such condition, the job is stopped and the entire lot of this particular material is rejected and delivered back to rough-stock inspection where it is put through a careful inspection, only such material as shows no defects whatsoever being placed back in rough stores.

A number of major parts, such as crankcase sections, receive 100 per cent inspection on each operation. On items of this kind each acceptable operation is stamped with the inspector's number.

This marking insures the operator taking up the next operation that previous operations are in accordance with the drawing dimensions and quality standards. However, aluminum alloy, known for its peculiar tendency to change its shape and size after the removal of stock from certain sections, necessitates 100 per cent inspection after each machining operation and the enameling operation which requires heating the crankcase to 200 deg. fahr. for approximately two hours in order to bake the enamel and give an acceptable finish. (Fig. 5.)

## Final Inspection

Upon completion each engine part is thoroughly washed and cleaned and sent to one of several final inspection cribs where it is given 100 per cent final inspection. The inspection cribs are well lighted, well ventilated, and equipped with the most modern precision instruments, such as thread comparators with high magnification for accurately checking pitch, diameter, and lead of threads, fluid gages, and amplifying gages for detecting taper or-out-of round condition on close-dimensioned parts. (Fig. 6.)

Each acceptable piece is stamped by the inspector, each inspector using his own identification number, so that any part can be traced back to the inspector making final inspection. In the case of hardened pieces, the inspector's number is etched.

Parts which pass final inspection are delivered to finished stores for issue to the assembly department. After assembly each engine is given a production test, following which it is disassembled and all parts carefully examined for defects which might have developed while the engine was being operated under power. The engine is then reassembled and, after final test, is thoroughly washed and cleaned and given a final inspection for appearance and check against the sales order as to accessories furnished before being sent to the packing department to be ready for shipment.

# High-Speed Gearing

## Some of the Requirements of High-Speed Reduction Gears and How They Are Attained Commercially

By IRA SHORT,[1] SOUTH PHILADELPHIA, PA.

IT IS A KNOWN fact that steam turbines, in order to attain their maximum efficiency, must operate at comparatively high speeds, and that for the same reason some of the apparatus which they drive, such as pumps, propellers, d.c. generators, etc., must operate at much slower speeds. Some method of speed reduction must therefore be employed, and in order for it to be successful it must be efficient, silent in operation, reliable, and of long life. All of these requirements are met in correctly designed and carefully manufactured helical-tooth gearing.

The points brought out in this paper are limited to reduction gears furnished by the Westinghouse Electric and Manufacturing Company, which up to the present time has built more than 3000 geared units ranging from 5 to 32,500 hp. and totaling well above 2,500,000 hp.

The first gear manufactured by the company, shown in Fig. 1, was a 6000-hp. experimental one built in 1909. It was necessary to have the pinion and wheel for this gear cut in Germany as there was no machine in this country large enough for the purpose. The test of the gear was very successful, and the efficiency was found to be more than 98 per cent. It is customary to guarantee an efficiency of from 97.5 to 98.5 per cent for single-reduction gears, and from 95 to 97 per cent for double-reduction gears.

Fig. 2 shows the results of an efficiency test of a 1500-hp. double-reduction gear reducing from 3360 r.p.m. to 90 r.p.m. These tests were run by connecting a turbine first to a water brake and carefully calibrating the former for various powers and speeds with a given steam condition. The turbine was then connected to the same brake through two sets of identical reduction gears, the slow-speed shafts of which were bolted together. The high-speed pinion of one gear was connected to the turbine, and the high-speed pinion of the other to the brake. Then by operating the turbine under duplicate conditions as when direct-connected to the brake, the difference in power absorbed by the brake, with the gears in use, indicated the loss of power due to the gears. Assuming the loss of each gear to be equal, the curves in Fig. 2 show how the efficiency of a gear varies with the load and speed.

In running this efficiency test care was taken to maintain the viscosity of the oil constant, as it was found that the gear loss was almost directly proportional to the viscosity of the oil.

### Action of Gears

A correctly designed gear should, if properly operated and barring accidents, have a life equal to that of the driven and driving machines. Correct design proportions insure that the parts will be amply large to transmit the power. This is especially true as regards the teeth.

Fig. 3 represents a section of a pair of meshing teeth in three typical positions. Figs. 4 and 5 are the velocity diagrams for the positions *c* and *a*. At position *b* the lines representing the velocity of the pinion and wheel will coincide, or there will be true rolling and no sliding. From these figures it can be seen that the motion between the teeth is a combination of rolling and sliding, and that while the rolling is always in the same direction, the sliding is toward the pitch line on the wheel tooth and away from the pitch line on the pinion tooth.

The action may be summarized as follows:

| | Rolling | Sliding |
|---|---|---|
| Pinion tooth, Fig. 6....... | Root to tip | Away from pitch line |
| Wheel tooth, Fig. 7........ | Tip to root | Toward pitch line |

This is shown diagrammatically in Figs. 6 and 7, the straight arrows showing the direction of sliding and the curved arrows the direction of rolling. An examination of these diagrams shows that with gear teeth there are only two types of motion, namely,

*a* Fig. 8, rolling combined with sliding, both being in the same direction; and

*b* Fig. 9, rolling combined with sliding, in *opposite* directions.

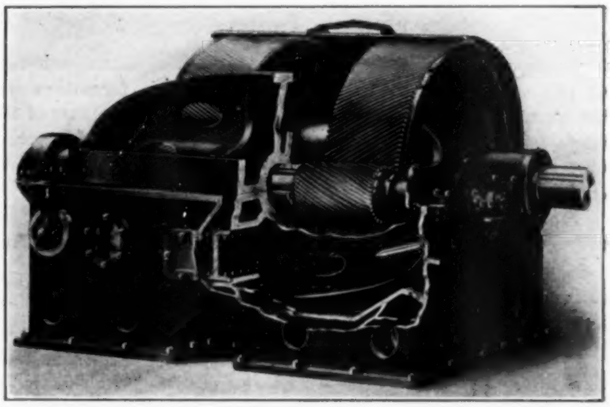

Fig. 1 6000-Hp. Experimental Gear

Further, it will be seen that above the pitch line both on the pinion teeth and on the wheel teeth the motion is of the (*b*) type, while below the pitch line it is of the (*a*) type.

Above the pitch line the action will be conducive to the production of a polish, but below it the conditions will not be so favorable. The following may be approximately what occurs; Because of the elastic nature of the material the slipping will be more or less jerky, thus tending to form the surface material into small ridges. Below the pitch line the motion will tend to leave these ridges behind, while above it the motion will tend to smooth them out. This action is represented diagrammatically in Figs. 8 and 9.

Tests have shown that abrasion is much more rapid with the (*b*) type of motion than with the (*a*) type.

### Wear of Gear Teeth

There are two distinct types of abrasion or wear occurring at the meshing faces of gear teeth:

1 A regular change in the shape of the tooth profile, and

2 The formation of a number of cavities or pits on the tooth face.

A good illustration of the first type of wear is shown in Fig. 10. This is reproduced from a photograph of an ink impression

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made from some worn pinion and gear teeth. The original tooth shape has been drawn in to show better the wear that has taken place. It will be seen that the wear varies considerably over the profile, and is greater below the pitch line than above.

Even with the great amount of wear indicated, these teeth meshed together well as indicated in Fig. 11, and seem to have developed an "enveloping" tooth which has been tried out in an endeavor to obtain more contacting tooth surface.

There is considerable wear at the tips of the gear teeth, but very little at the pitch line. It has been found in several installations that the metal flowed because of the combined rolling and sliding action until the thickness of the gear teeth at the pitch line after being in operation for some time was actually greater than when the gear was originally put in service. And it is believed that the metal flowing from the tips of the gear teeth has maintained the pitch-line thickness very close to the original thickness. It is also found that the (*a*) type of motion drags metal off the pinion teeth, forming what is generally termed a "wire edge."

Wear such as that indicated here is usually due to the failure of lubrication of the teeth, allowing metal-to-metal contact. This particular gear was subjected to considerable vibration from the propeller, which seems to have punctured the oil film and so hastened the abrasive action.

### Wear Due to Pitting

Consider now the second type of wear, which is the formation of pits or cavities on the meshing faces. This formation has been explained in a number of ways such as actual seizure of the metals, pulling the metal out from one surface; explosive action of a particle of oil between the teeth, burning the tooth surface; and fatigue of the metal.

Fatigue of the metal seems to be the best explanation of this formation. The conditions are such at the point of contact between two meshing teeth that it is difficult to form an exact idea of the actual stresses set up. The stresses have been investigated by photoelastic methods, and it appears that a maximum shear stress occurs a short distance below the surface, and travels along with the point of contact. Should there be any slight imperfection in its path or some irregularity on the meshing surfaces, the stress will be considerably increased and by repeated application will cause a fatigue crack, and finally a pit.

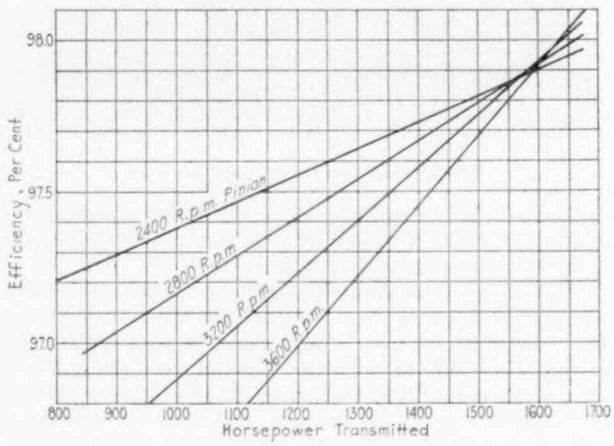



Fig. 2 Efficiency Test of 1500-Hp. Gear

Fig. 12 shows a photomicrograph of a pit. A small triangular piece was cut from a tooth, the pitted surface being on one side of this triangle. This was mounted in some low-fusing alloy and the whole polished together so that the edge of the specimen where this pitting occurred would not be disturbed by the polishing and the character of the metal at the extreme edge of the pitting could be studied. A peninsula of metal is seen standing out between pits and a distortion of the grains is evident at this point, the body of the steel being apparently normal.

A gear that has been in service for some time generally develops

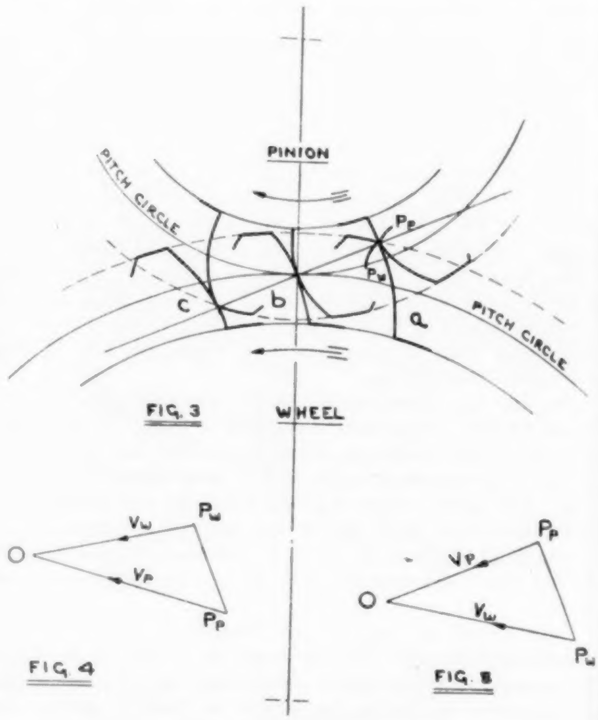
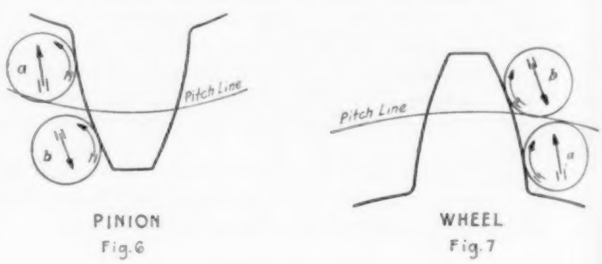



Fig. 3 Pair of Meshing Teeth

Fig. 4 Velocity Diagram, Position *c*

Fig. 5 Velocity Diagram, Position *a*



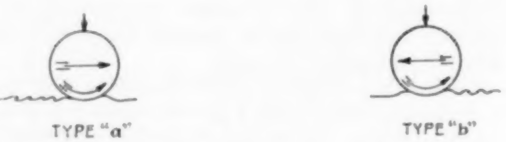




Fig. 6 Tooth Action, Pinion Teeth

Fig. 7 Tooth Action, Gear Teeth

Fig. 8 Rolling and Sliding in Same Direction

Fig. 9 Rolling and Sliding in Opposite Directions

a row of scattered pit marks along the pitch line of the gear teeth, and more or less widely scattered pitting on both the pinion and gear teeth. The row of pitting along the pitch line of the gear teeth is probably due to the excessive pressure carried at this point because of the building up of the metal. The scattered pitting is probably due to other high spots on the pinion and gear, with a resulting high pressure at these points. When it is remembered that in the generation of the involute curve by a series of cuts by a flat surface as indicated in Fig. 13 there are miniature corners left, it is possible that a corner of the gear tooth comes in contact with a corner of the pinion tooth.

Pitting is considered to be in the nature of a corrective agency as metal is removed from the high spots, allowing the surrounding area to carry their share of the load. It is found that pitting generally starts on a new machine shortly after it is put in service, and gradually decreases and finally stops completely after a few months.

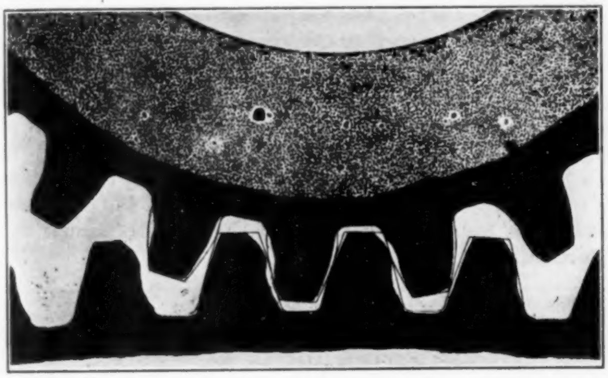


Fig. 10 Worn Teeth

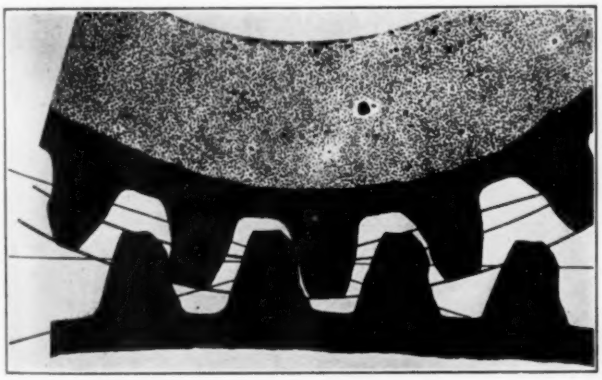


Fig. 11 Meshing of Worn Teeth

### Allowable Loading of Teeth

In practice, if correct alignment is maintained to insure uniform tooth contact, a tooth pressure of 100 lb. per lineal inch of width of face per inch of pitch diameter can be safely carried. With a 5-in. pinion a pressure of 500 lb. per inch of face can be used, and with a 10-in. pinion, of 1000 lb. A pressure of 320 lb. per inch of face per inch of diameter has been carried with no signs of failure.

The allowable load that can be continuously carried on a gear tooth is directly proportional to the radius of curvature of the contacting teeth. The radius of curvature of the tooth changes from the base to the tip, but for all practical purposes can be taken as being directly proportional to the pitch diameter. The pinion tooth, having the smaller radius of curvature, is more highly stressed and limits the allowable load.

In addition to the stress at the contacting surfaces, the tooth can be considered as a cantilever beam, and the tooth load tends to break the tooth at the root. If the number of teeth in the pinion is maintained constant with various diameters, the stress at the base of the teeth will be constant if the load is varied directly as the pitch diameter.

For some time a tooth shape that was much broader at the base was used to prevent tooth breakage. This was developed with a standard hob by cutting one less tooth than that corresponding to the blank diameter. If the blank was the theoretical diameter for, say, 27 teeth, then 26 teeth would be cut. This was designated as a "long-addendum tooth," as the pitch line was lower than standard.

Fig. 12 Photomicrograph of a Pit

Fig. 13 Generation of Involute

Theoretically there is less sliding with a long-addendum tooth

than with a standard tooth. The teeth in the position $a$ in Fig. 3 are well lubricated as the cavities between the approaching teeth are filled with oil. When the teeth reach the position $b$ there is rolling and the oil supply has been cut off by the following teeth, and from $b$ to $c$, lubrication is poor. With the long-addendum tooth the period of time between $a$ and $b$ was decreased and

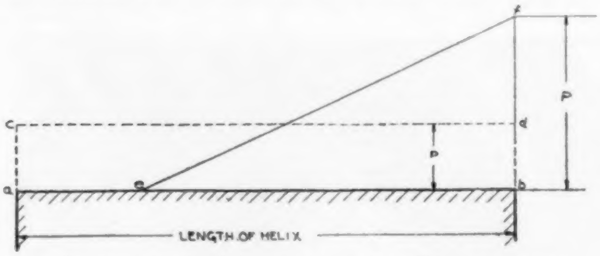



FIG. 14 CHART SHOWING LOAD WITH MISALIGNMENT

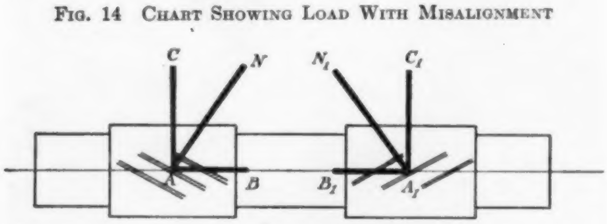
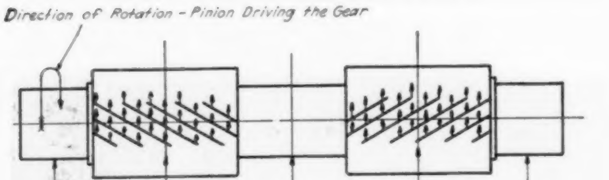


FIG. 15 LOADING OF GEAR TEETH



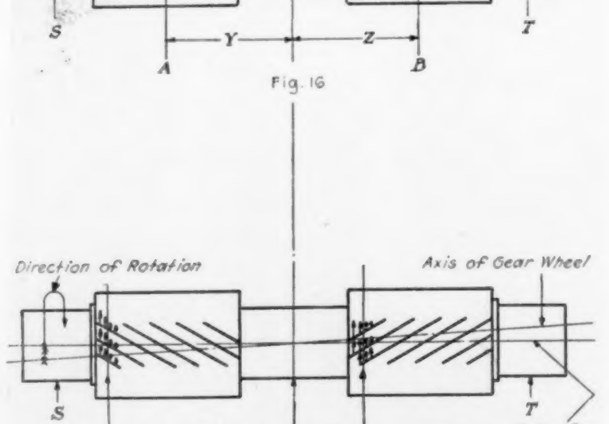




FIG. 16 UNIFORM TOOTH LOADING

FIG. 17 NON-UNIFORM TOOTH LOADING

the time between $b$ and $c$ was increased. The result was that lubrication of the teeth failed, and "scoring" or "galling" took place at the root of the gear tooth and the tips of the pinion teeth.

All gears with this type of tooth scored to some extent. Some stopped after one or two scrapings, while others continued to score. Some were remedied by turning off the tips of the pinion teeth to remove the metal causing excess sliding. The design was changed on other gears and a standard tooth shape was adopted, or the correct number of teeth corresponding to the blank diameter was cut.

It was found that scoring would take place on the second reduction of double-reduction gears more so than on the first. The relative amount of sliding and loading on each was the same. It would be thought that the high velocity of the first reduction would cause scoring, but it is now believed that the second-reduction teeth were in contact long enough to pierce the oil film, while the high-speed teeth, being in contact only about one-sixth as long, did not have time to do this.

Photoelastic studies have shown that teeth with a small radius at the root have a very high stress concentration at the base of the tooth. Special hobs having the straight sides of the cutting edges joined with a radius instead of being cut off flat on top generate a tooth with a large radius at the base and eliminate this high stress concentration.

## IMPORTANCE OF CORRECT ALIGNMENT

Correct alignment is essential to prevent overloading of the tooth surface. If the teeth are in line the tooth contact can be represented by the line $cd$, Fig. 14, where the pressure $P$ is uniform across the face and the total pressure is $ab \times ac$. If misalignment occurs the load may be carried by only that portion of the face represented by $eb$. For the same speed and power the area of the rectangle $acdb$ must equal that of the triangle $ebf$. Therefore

$$ab \times bd = {}^1/_2\, eb \times bf \quad \text{or} \quad \frac{bf}{bd} = \frac{2ab}{cb}$$

If we assume $eb$ equal to $^3/_4\, ab$, then

$$\frac{bf}{bd} = \frac{8}{3} = 2.67$$

This shows that on any gear where misalignment is likely to occur the allowable tooth pressure, assuming uniform contact, must be kept low to insure that the pressure under misalignment conditions will not be excessive.

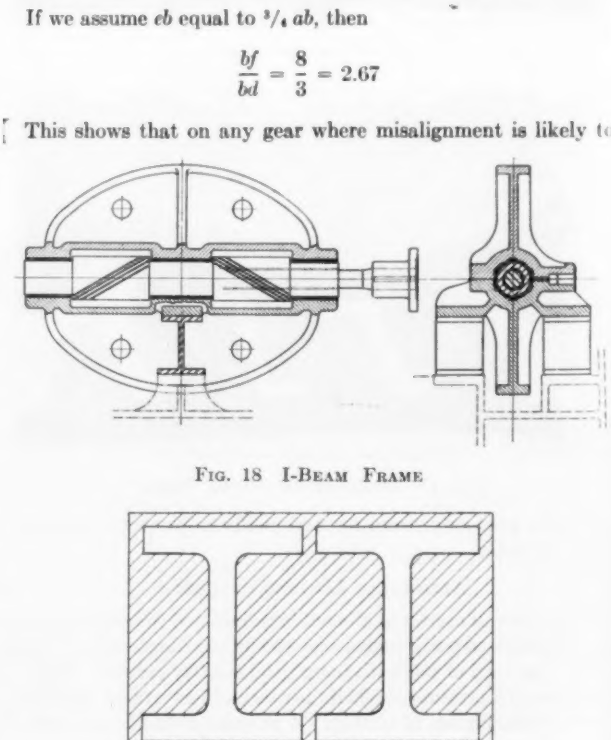


FIG. 18 I-BEAM FRAME

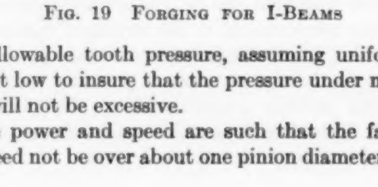


FIG. 19 FORGING FOR I-BEAMS

When the power and speed are such that the face width of each helix need not be over about one pinion diameter, the pinion

and wheel may be supported in bearings rigid with the housing if the designed pressure is not too high.

Our practice is to make all gears below about 500 hp. of rigid or fixed-bearing design. Above 500 hp. we use the floating-frame design which allows the pinion to automatically maintain correct alignment with the gearwheel.

With rigid bearings a certain amount of misalignment is expected with the resulting concentration of load. The two shafts may be aligned perfectly to give uniform loading with a uniform temperature of the housing. The housing is apt to be distorted either from bolting it to its seating, or the bearings may operate at different temperatures, causing one corner of the housing to raise more than another. It requires only a very small amount of misalignment to cause concentration of load.

With turbine-driven gears the pinion runs at speeds of from 3,000 to 10,000 r.p.m. At high pitch-line speeds trouble may be experienced in lubricating the gear teeth as the centrifugal force throws the oil off the teeth. Also any hammer blow due to slight inaccuracies of the contacting teeth varies as the square of the velocity of the teeth. The pitch-line speed is generally held below 120 ft. per sec., although speeds of 140 ft. per sec. are not unusual and speeds as high as 200 ft. per sec. have been used.

The pitch-line speed limits the pinion diameter for any speed of revolution, and for increased power at that speed it becomes necessary to increase the face width. A face width as high as five pinion diameters has been used, although the maximum is

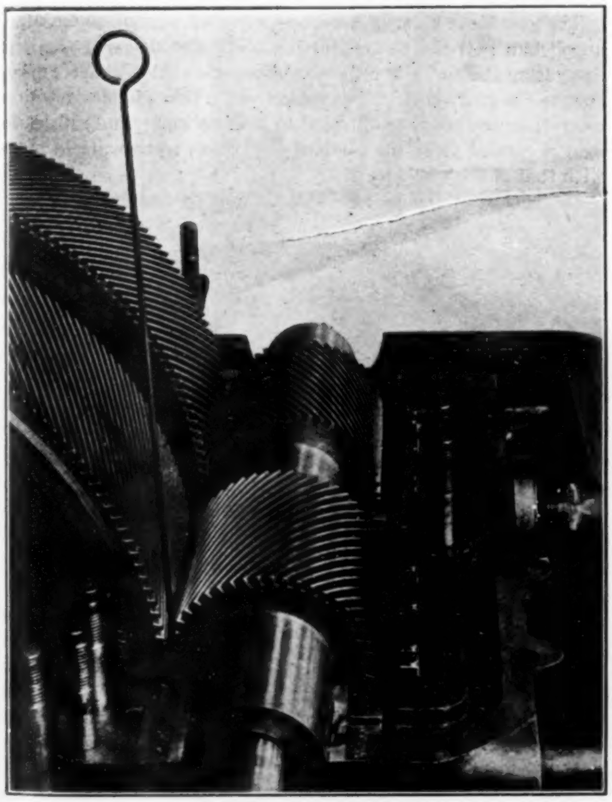


Fig. 20 Use of Block Gages

generally held to four diameters or less. A long pinion is liable to have concentration of load at the ends of the face on account of deflection between the bearings. With a total face width of more than three diameters a center pinion bearing is necessary.

All high-speed gears at the present time are cut with helical teeth as the tooth action is much smoother than is possible with spur gears. The teeth slide into mesh instead of coming into mesh abruptly as do spur gears. The helical angle varies from 20 deg. to 45 deg.

With helical teeth the actual tooth pressure is normal to the

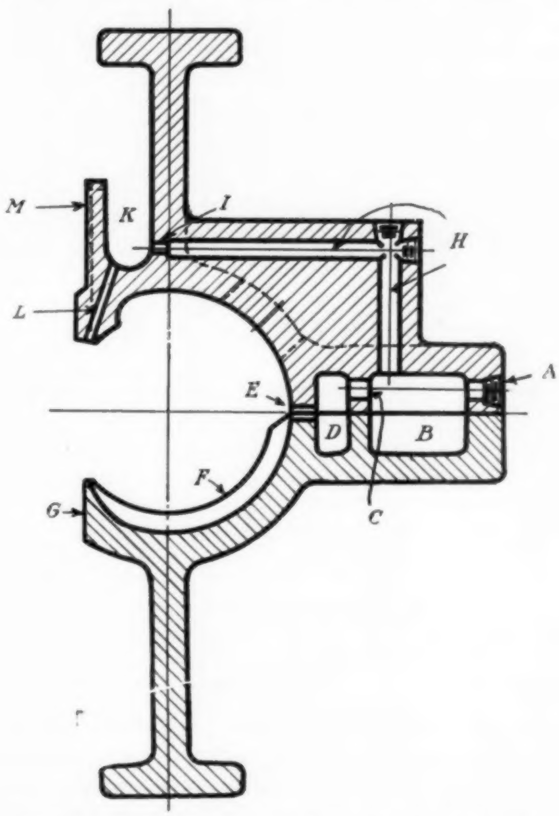



Fig. 21 Section of Frame Showing Oiling System

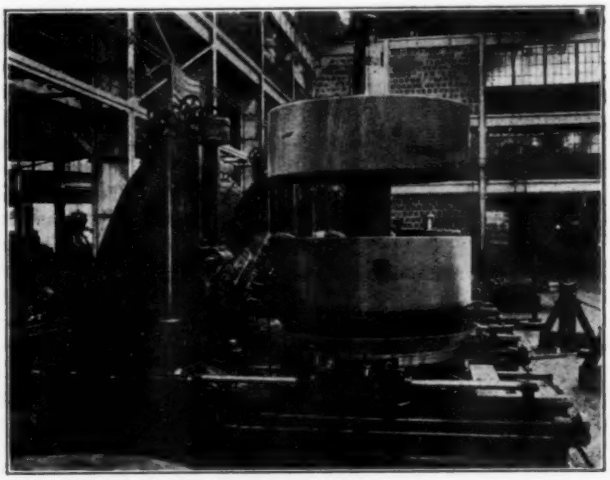


Fig. 22 Gear Hobber

tooth as represented by $AN$ in Fig. 15. This force can be assumed to be divided into two components, $AB$ parallel to the axis and $AC$ tangential to the pitch line and normal to the axis. The force $AC$ is the tooth pressure generally spoken of with reference to gears.

The pinion is generally connected to the drive with a coupling allowing free axial motion. Therefore $AB$ will be equal to $A_1B_1$, and as the helical angles on the two helices are equal, $AC$ will be equal to $A_1C_1$. The loads carried by the two helices will then be equalized.

If the tooth pressure is uniformly distributed across the face this tooth pressure can be considered as concentrated in the center of the helix or equidistant from the center of the pinion as shown in Fig. 16.

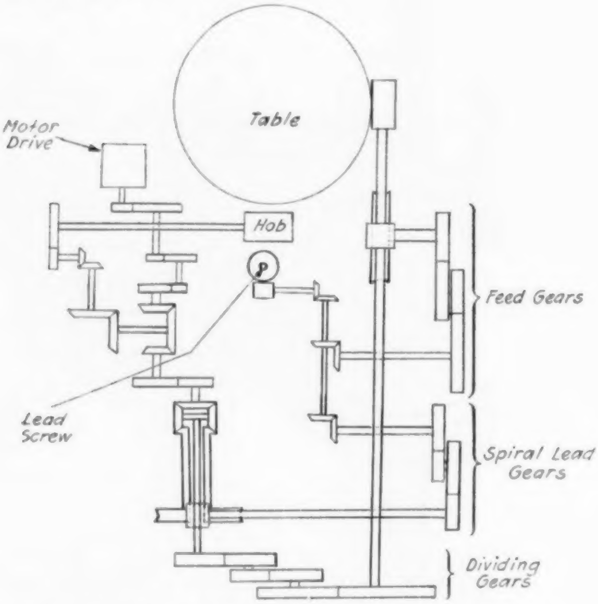



Fig. 23 Showing Arrangement of Hobber Gearing

If there is misalignment the conditions will be as represented by the triangle in Fig. 14, or it can be considered as $A$ concentrated at distance $Y$ and $B$ at distance $Z$ from the pinion centers, Fig. 17.

It has just been shown that the total pressures on the two helices are equal, therefore with misalignment there is a resulting moment $AY - BZ$ tending to rock the pinion about the center bearing to bring it back into line. If the pinion is supported at the center in such a way that it is free to rock it will automatically align itself.

This may be accomplished in a practical manner by supporting the pinion as shown in Fig. 18. The pinion is supported by three bearings which are mounted in a heavy frame. This frame is very rigid in order to maintain the three bearings in alignment. The frame is fastened to the gear housing by means of two I-beams the top web of the beam being bolted to the frame and the lower web to the housing. The flexure of the vertical web of the I-beam allows a limited rocking motion of the frame with very little restriction.

The movement of the frame is minute and may be only in the neighborhood of 0.001 in. at the end of a 4-ft. pinion, thus the bending stress in the web of the I-beam is very low. The web is in either tension or compression to the extent of the tooth pressure. This amounts as a rule to less than 10,000 lb. per sq. in. The I-beams are made of forged steel and are annealed after being rough-machined to approximate size.

It is known that the weakest part of a forging is at the center. Forgings for these I-beams are therefore made large enough to machine into two I-beams as indicated in Fig. 19, the center part being then discarded, leaving sound metal for the vertical web of the I-beam.

The horizontal component of the tooth pressure is carried by struts at either end of the pinion frame. These struts limit the motion of the frame to a vertical plane in the case of a side-pinion gear. The correct center distance is obtained by calculation. On either end of the pinion and wheel are turned collars a little below the root of the teeth. Block gages are made which when just fitting between the collar indicate the correct center distance. The struts are adjustable to allow this block gage to just fit below the collar, as shown in Fig. 20.

It is sometimes thought that this frame is intended to compensate for inaccuracies of gear cutting. This is not the case as the frame is only supposed to take care of misalignment between the pinions and wheel. It has been found, however, that inaccuracies in gear cutting are indicated by a working motion of the frame with each revolution of the wheel. If such is found to occur the teeth are recut to correct the error, and if necessary the hobbing machines are corrected.

In comparing the tooth pressures on different gears, the probability of misalignment must be considered with its resultant load concentration, also the total load-carrying surface of the tooth. If we take a pair of gears with teeth of normal height and turn the tips off the pinion and gear teeth until the working depth of the teeth is about one-half what it was at first, we shall have doubled the tooth pressure per inch of contact on the tooth, even though the tooth pressure per lineal inch of face is the same.

## Lubrication of Teeth

The gear teeth must be copiously supplied with oil to maintain an oil film between the contacting teeth and to carry the heat away from the pinion in order to maintain it at the same temperature as the gearwheel. The pinion teeth, being in contact more often than the wheel teeth, tend to heat up more, and unless the heat is carried away the pitch of the pinion teeth will not agree with that of the wheel teeth.

In order that the pinion shall be well bathed in oil without circulating an excessive quantity, the oiling system shown in Fig. 21 has been adopted and has proved very satisfactory. Oil is admitted to the frame through a flexible oil connection from the housing, and flows into a passage which extends for the full length of the frame, supplying oil to the three pinion bearings and to the teeth. Oil is supplied to the teeth from oil pans formed in the pinion frame.

Fig. 24 Construction of Master Wormwheel

With correct alignment and well-lubricated teeth the life of a gear is indefinite. Gears with self-aligning floating frames and lubricated as described above have been in practically constant service since 1911 with no appreciable wear of the teeth. The marks left when the high spots were scraped off on first starting the machine are still visible.

If, however, the teeth are subject to severe vibration due to misalignment of the coupling connection to the driving or driven

machine or to torsional disturbance from either, the teeth will deteriorate. It will generally be found that the deterioration will go only so far until the teeth will have taken a new form such that more surface is supporting the load. This was found to occur with the gear of Fig. 10. It will be noted from Fig. 11 that there is a large surface supporting the load instead of a line contact.

### Noise in Gears and Its Elimination

Experience has shown that noise from a gear can be traced to one or more of the following sources:

1 Errors of hobber reproduced in gear.

Fig. 25 Resonator

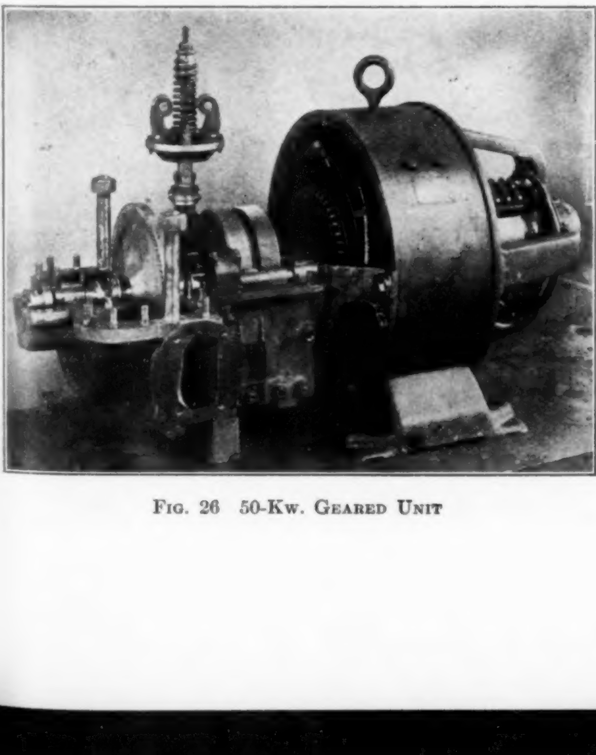


Fig. 26 50-Kw. Geared Unit

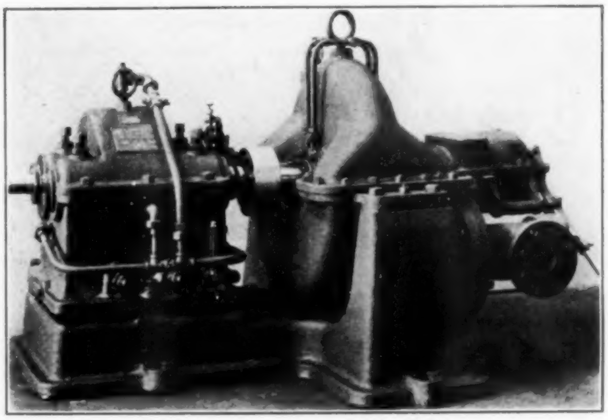


Fig. 27 150-Hp. Geared Turbine

2 Variable deflection of gear teeth with phases of tooth contact.

3 Vibration transmitted from connected machines.

Fig. 22 shows a gear-hobbing machine, and in Fig. 23 its gearing is shown diagrammatically. It is necessary that the accuracy of this machine be as great as possible, because any errors in it will be reproduced in the gear that is being cut. This is especially true of the master wormwheel which rotates the gear blank while it is being cut. If the circumferential pitches of the teeth are not equal in the master wormwheel, the teeth being cut will not be pitched accurately and the result will be a noisy gear.

Fig. 24 shows the construction of the master wormwheel used in order that the errors of circumferential pitch shall be the minimum. By having the wormwheel split as indicated, one half can be revolved with reference to the other half. It is originally cut on the same machine or a similar one on which it is to be used by a hob which is a duplicate of the worm which will drive it. One half of the wheel is then turned 180 deg. with reference to the other. The teeth are matched up on one side, and if spaced accurately all teeth will match. The amount the teeth overlap indicates the accumulation of circumferential error in pitch.

The wormwheel is then bolted together and doweled. It is placed in its position in the hobbing machine and driven by a cast-iron worm. Abrasive is placed between the teeth which grinds away the overlap. The halves are again separated and turned, say, 90 deg. or until the maximum overlap in error is determined, and the teeth are again lapped in. Each lapping reduces the existing error approximately one-half. The process is repeated with different relative positions of the two halves until no appreciable error can be found.

The machine is then assembled with a bronze worm made to fit the teeth of the wormwheel.

The hobbing machines are checked occasionally with test rings made in halves, similar to the master wormwheels. These rings are generally 100 in. in diameter and are cut with any convenient number of teeth. For convenience in measuring the error, spur-gear teeth are cut. One-half of the ring is then revolved until the maximum errror is determined. On a machine recently checked the maximum accumulative error on a 100-in. wheel was found to be 0.002 in. When it is considered that this wheel was cut with 400 teeth and an error in 200 teeth was then 0.002 in., or the error in pitch from tooth to tooth was only about 0.00001 in., we begin to realize the accuracy of the machine.

It has been found that the wormwheel driving the table should be supported on journals which are an integral part of the worm to insure against the worm's revolving with an eccentric motion and thus causing the table to be accelerated and retarded with

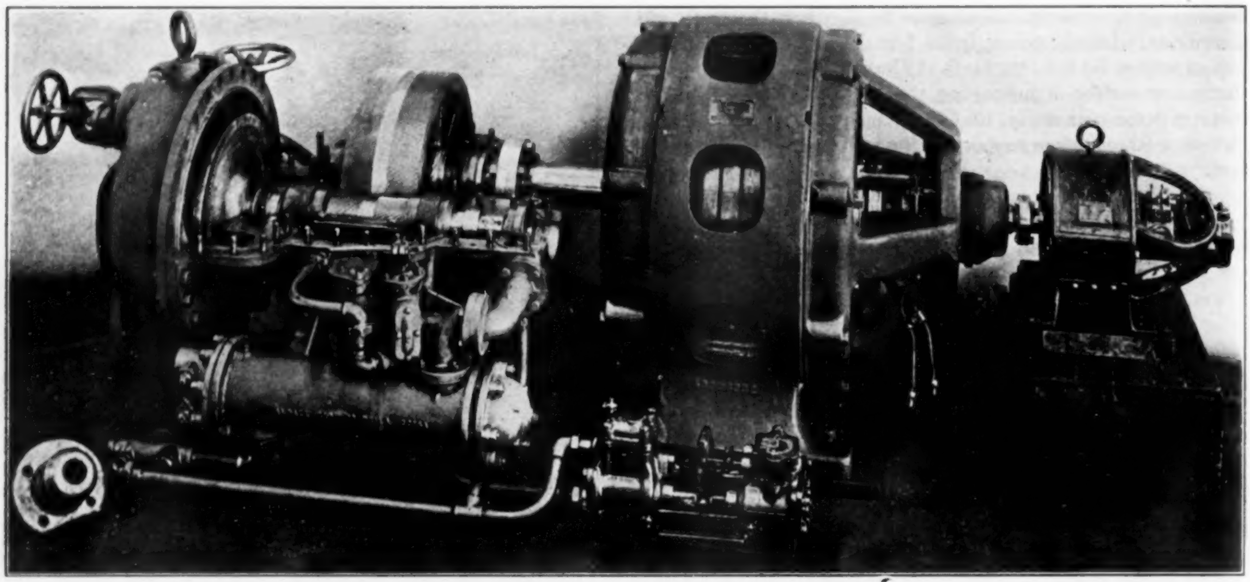


Fig. 28 200-Kw. Geared Unit

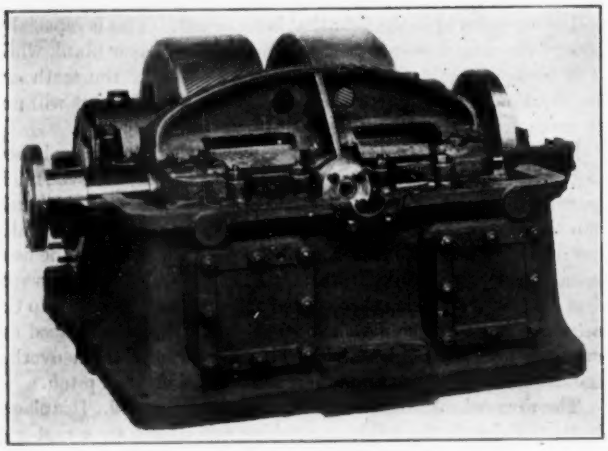


Fig. 29 1000-Kw. Reduction Gear

each revolution of the worm. Also the shaft driving the worm should be extra heavy to preclude torsional vibration, with the same result to the gear being cut.

It is also desirable that the hob be supported on journals which are an integral part of the hob to prevent an eccentric motion of the hob. This is practically impossible owing to the cost of the hob. The hob can be tested for eccentricity after being mounted on the arbor of the hobbing machine, if the ends of the hob are ground true with the bore for about $^1/_4$ in. from each end.

In addition to the master wormwheel, all other parts of the machine are occasionally checked to see if the desired accuracy is maintained. The lead screw, for instance, which raises or lowers the hob is checked periodically and must not show an error exceeding 0.0005 in. per foot in length.

The change gears should be recut occasionally to insure that they transmit a uniform angular velocity.

It has been found that the hobbing machine cannot be made accurate enough to prevent very small errors from being reproduced in the blank being cut.

With every revolution of the worm driving the table the gear blank is accelerated and retarded. This is because the worm does not transmit a uniform angular motion to the table. If there are 120 teeth in the master wormwheel this error will be repeated every 3 deg. This angle is termed the "angle of error." There is less error if a "Hindley" or hourglass worm is used, but the error cannot be entirely eliminated.

It has been found, however, that the remaining small errors cannot produce a noise if care is taken to cut the gear on a machine having sufficient teeth in the master wormwheel to bring the "angle of error" well within the "angle of contact." The angle of contact is that angle measured by the line of contact.

With the angle of contact less than the angle of error, the angular velocity of either the pinion or wheel is continually varying, which sets up a sound wave for each error. If the angle of contact is greater than the angle of error, we bridge across the error and obtain a uniform angular velocity of both pinion and wheel.

It has been found that unless the teeth are so proportioned as to give a constant deflection at all phases of engagement, sound waves will be set up because of this deflection. By making

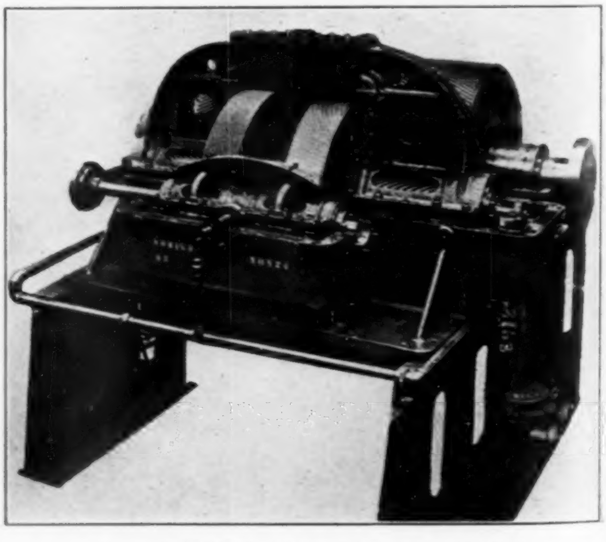


Fig. 30 2000-S.Hp. Marine Reduction Gear

the line of contact exactly two pitches long and also the face width of each helix an integral number of axial pitches wide, the tooth deflection will be constant.

To obtain the best results, two or more cuts are required to finish the teeth. Generally the first cut finishes the tooth to within about 0.010 in. of the finished size, and the finishing cut brings the teeth to size.

On the smaller gears of the rigid-bearing design the two helices of the gearwheel are cut in a single-piece rim. It has been found necessary to take the roughing cut on both helices before taking the finishing cut, otherwise the finished teeth on the first helix will be distorted by the roughing cut on the second helix.

On the pinions of these gears it has been found desirable to rough-turn the bearings and faces and rough-cut the teeth before grinding the journals to size. The finish cut is made after grinding the journals, and the pinion is centered in the hobs to the ground journals to insure its running true.

On all sizes of gears it is essential that the gear center be properly annealed to relieve all internal strains and insure its keeping its shape after the teeth are cut. The wheels are generally built up of a cast-iron center, forged-steel shaft, and forged-steel rim.

The rim is made of heat-treated carbon steel having 0.20 to 0.30 per cent carbon. The pinions are made from heat-treated carbon steel having 0.50 to 0.60 per cent carbon. For the smaller-size gears pinion material can be purchased in bar stock ready heat-treated. The larger gears using the floating-frame construction have a hollow pinion fitted with an internal flexible drive shaft of chrome-nickel steel.

### Analysis of Gear Noise

To analyze the noise emitted from a gear it is necessary to be able to trace its origin in order to determine the cause. A very simple instrument for this purpose is shown in Fig. 25. This consists of a small portable cylinder and piston connected to ear pieces. The piston is moved in the cylinder until the air column in the latter is in resonance with the sound from the machine,

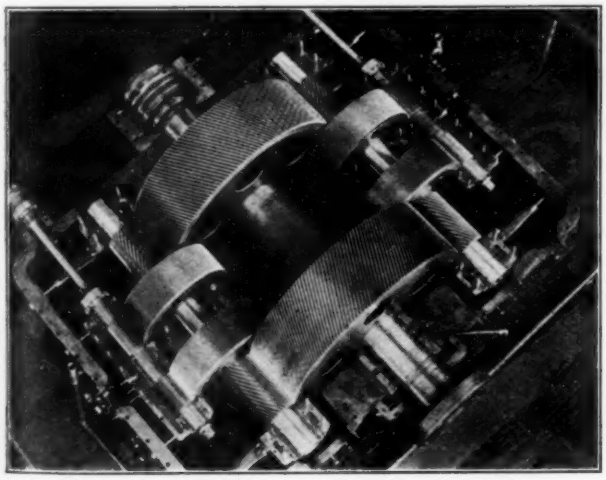


Fig. 31 3000-S.Hp. Marine Reduction Gear

when the sound will be heard distinctly. In using this "resonator" the length of the air column is first made very short and gradually increased in length until the maximum sound is heard, when the length of the air column is noted. The piston is then moved further until the same note is again heard, and the length of air column is noted. The distance between these two points is then exactly one-half wave length of the sound. Knowing the velocity of sound to be about 792,000 in. per min. under average conditions and by noting the speed of the machine at the time of checking the sound wave, the sound waves per revolution can be determined from the formula—

$$\text{Waves per rev.} = \frac{\text{Velocity of sound, inches per minute}}{\text{R.p.m. of machine} \times \text{wave length in inches}}$$

Knowing the waves per revolution, the source of the sound can generally be traced. A hobbing-machine error will generally

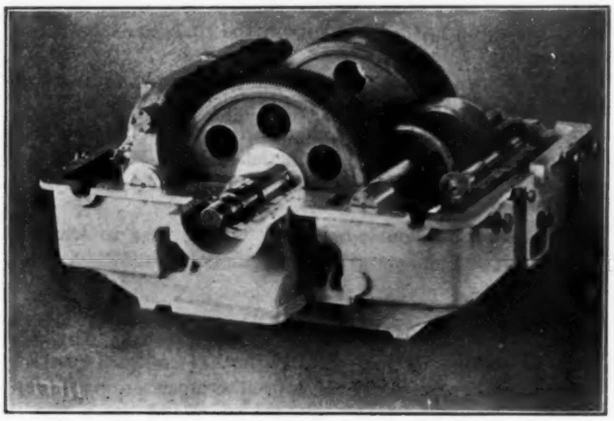


Fig. 32 Model of 3000-S.Hp. Marine Reduction Gear Shown in Fig. 31

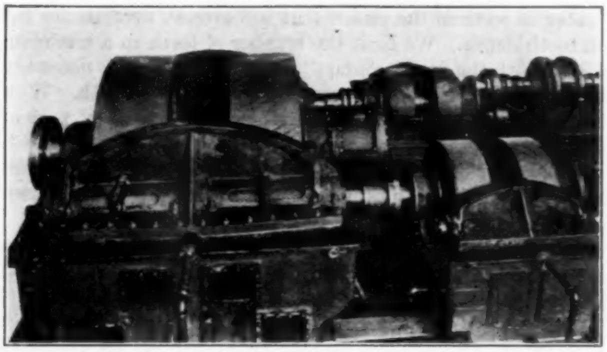


Fig. 33 5500-S.Hp. Marine Reduction Gear

show up as the same number of sound waves per revolution as there are teeth in the master wormwheel.

On all gears a note will be heard corresponding to one sound wave per tooth on the wheel. This note can be reduced to a minimum by using the "even contact" design, which insures a constant deflection of the teeth.

### Typical Gears

Fig. 26 shows a 50-kw. generator set. This has a fixed bearing gear having the gearwheel overhung from the generator shaft. Lubricating oil is supplied by a gear pump driven from the governor shaft. The speed reduction is from 7200 to 1200 r.p.m.

Fig. 27 shows a fixed-bearing gear usually employed with a steam turbine for pump or blower drive. It is often used with motor drive as a speed-up gear. When employed with a turbine the inboard turbine bearing is omitted and a rigid coupling used, making the turbine rotor and pinion a three-bearing set. This type of unit is used for powers up to 500 hp. An oil pump on the end of the gear shaft supplies oil to the gear and turbine bearings.

Fig. 28 shows a 200-kw. generator set comprising a fixed-bearing geared turbine having the turbine rotor overhung from the pinion. These sets are built in sizes from 75 to 500 kw. An impeller on the end of the pinion serves as a governor for the turbine, and part of the high-pressure oil is used in an ejector for supplying the bearing oil. The reduction is from 6000 r.p.m. to either 1700 or 900, depending on the generator used.

Fig. 29 shows the type of gear used for the larger power-generator drives and made in sizes of from 500 to 3000 kw. The reduction is generally from a turbine speed of 3600 r.p.m. to either 514, 720, 900, or 1200, depending on the characteristics of the generator.

Fig. 30 shows a double-reduction marine gear to transmit 2000 s.hp. on a single pinion with a reduction of 3680-438-90 r.p.m.

Fig. 31 shows a double-reduction marine gear to transmit 3000 s.hp. on two pinions with a reduction of 3340-585-90 r.p.m.

Fig. 32 shows a one-eighth-size model of the gear shown in Fig. 31.

Fig. 33 shows a double-reduction marine gear to transmit 5500 s.hp. on two pinions with a reduction of 3500-578-95 r.p.m.

## Discussion

THE discussion of the paper took the form of a series of questions which, with their answers, have been summarized as follows:

Nikola Trbojevich[2] asked whether we would use a fine or coarse pitch if we had a set center distance. He also asked if the strongest region of the gear is at the pitch line. Our practice with a fixed center distance is to use the smallest number of teeth in the pinion that will give an involute for the full tooth depth. We limit the number of teeth to a minimum of 31. With the "even contact" design it is generally necessary to increase the number of teeth by using a finer pitch. With the teeth having a large radius at the root the weakest part of the tooth seems to be the point of engagement. The teeth will generally wear out before breaking off. A well-lubricated tooth will show very little or no wear. Our experiments have shown no difference in the amount of noise with fine and coarse pitch.

H. J. Eberhardt[3] asked if we have had any trouble removing the abrasive after lapping the master worm wheels. We have had no trouble of this nature.

A. B. Zaenglein[4] asked if the lubricant made any difference in the noise. We have found that a very heavy lubricant reduces the noise to some extent but we have also found that the loss is directly proportional to the viscosity of the oil. To have the most efficient gear, the lightest oil possible should be used.

It has been asked if pitted teeth wore themselves in. Pitting is generally a corrective action and the teeth will wear in to fit each other. The teeth shown suffered excessive wear due to vibration from the propeller which punctured the oil film between the teeth.

It has been pointed out that on tests run with an even number of teeth in contact on slow-speed gears, no improvement could be noted over the gear not having an even number of teeth in contact. Most of our experiments have been made on high-speed gears and we have been able to make a gear more noisy by turning off the teeth and then make the same gear quieter by turning off still more of the teeth. It seems to be possible to distinguish the high pitch more easily and also to note variations in sound of high pitch.

It has been asked if with a set of four gears with different numbers of teeth, we could, using the resonator, trace the sound to determine which particular gear was at fault. The resonator will determine the wave length of the sound or the number of sound waves per minute. If one of the gears operates at a speed such that the product of the number of teeth and the r.p.m. is equal to the number of sound waves per minute, it is pretty surely to be the gear at fault.

It has been asked whether after getting the worm wheel perfected it was possible to get a worm that works correctly with it. The worm is ground to suit the final gear. The worm does not drive the table at a constant speed and it is necessary to have enough teeth in the master wheel so that the "angle of contact" overlaps the "angle of error," as described in the paper.

It was asked how much backlash is allowed. On all gears of all sizes and with all pitches the pinion is placed tightly in mesh with the gear and then they are spread apart 0.0004 times the center distance in inches plus 0.004 in.

It was asked if we have ever tried to eliminate the noise by altering the design of the gear case. We have tried lagging the gear cases and making them of cast iron as well as steel, and the only cure seems to be to eliminate the cause.

[2] Timken-Detroit Axle Co., Detroit, Mich.

[3] Newark Gear Cutting Machine Co., Newark, N. J. Mem. A.S.M.E.

[4] Proprietor, Niagara Auto Repair Shop, Buffalo, N. Y.

# The Pratt & Whitney Gear-Shaving Process

By H. D. Tanner,[1] Hartford, Conn.

The two present methods of generating involute gear teeth, both spur and helical, in soft gear blanks are the hobbing method and the gear-shaper method. Both come under the classification of forming-generating in that the form of the gear tooth generated, while it differs from the form of the cutter used, depends partly upon the form of the cutter.

Gears are usually hobbed at the angle at which they are to run; that is, a 20-deg. gear is hobbed with a 20-deg. hob. A 20-deg. gear can be hobbed at an angle greater than 20 deg. and also at a lesser angle, and even down to 0 deg. although a hob is an impractical tool at very small angles.

Gears are also usually shaped at about their running angle, although the generating angle could be varied slightly if there were reason for it. The shaper cutter, however, cannot generate involute teeth of any practical height at small angles. For instance, the smallest angle at which a 21-tooth cutter can generate a full involute on a standard full-height 15-tooth gear is 16 deg., 9 min., and 1 sec.

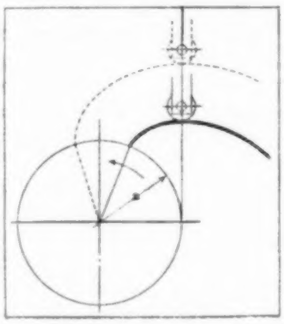


Fig. 1 The Involute as a Cam

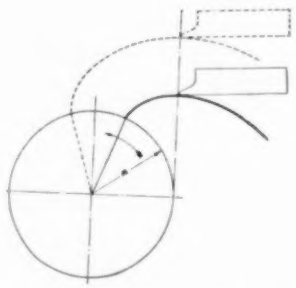


Fig. 2 Shaving the Involute

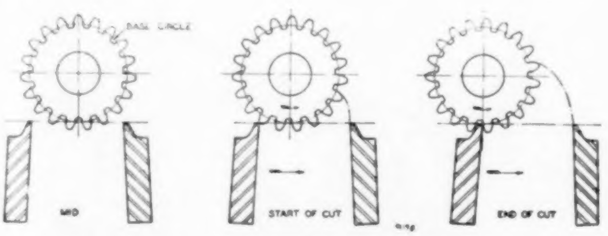



Fig. 3 Cycle of Shaving Machine

The gear-shaving process, the invention of James H. Barnes, of Dayton, Ohio, is a practical method of generating involute spur or helical gears at 0 deg. Acknowledgment is given the able and generous cooperation of the Chrysler Corporation in the development of the process.

The involute curve is generated by a point in a straight line rolling on a circle. A simple conception of this curve, as in Fig. 1, is that of a uniform-rise cam where the rise per revolution along a line tangent to a circle or radius $a$ is equal to the circumference of the circle. If this cam is revolving at a uniform rate in the direction shown by the arrow, the cam roll will rise at a uniform rate. If the cam revolves in the reverse direction, the roll will fall accordingly.

If now, as in Fig. 2, we place a roughed-out cam on the same center, set a cutting tool with its edge on the tangent line, and cause it to move up or down with the cam roll, the revolution of the rough cam against the cutting edge will remove the surplus material and leave the second cam exactly like the first or master cam.

In the actual machine a large cam, with two opposed involutes, and two cam rolls are used. Two cutting tools also are used, and the cycle is as shown in Fig. 3. At the left the gear is in the starting or loading position, and the tools are shown with their cutting edges on a line tangent to the base circle of the gear. In the center the gear has revolved in the direction shown by the arrow, the tools have been moved at exactly the correct rate to the right along the tangent line, and the left-hand tool has started to cut an involute curve on a tooth. At the right the same tool has come into contact with the base circle of the gear and has completed its cut. At this point the movement of the gear is reversed, the tools move back to the left, and the right-hand tool, following the path of the dot-and-dash line, finally cuts an involute on a tooth. The gear is again reversed, and while the tools are returning to their original position it lags behind just enough to index one tooth.

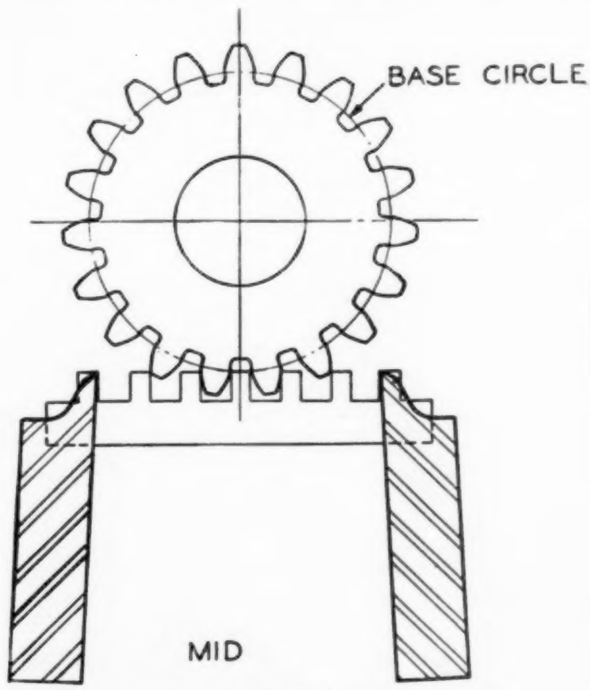



Fig. 4 Zero-Degree Rack-Generation Analogy

It now becomes apparent that the process is one of zero-degree generation and that the active profiles of the gear teeth are generated by rolling the gear in mesh with a zero-degree rack, as in Fig. 4. The active profiles of this rack are the top edges of its teeth, which coincide with the cutting edges of the tools. The remainder of the profile of the rack does not come into contact with the gear. We are then required to make tools with straight cutting edges slightly longer than the face of the gear to be cut and to place the tools in the shaving machine with their edges lying in a plane tangent to the base cylinder of the gear. If the

[1] Manager Gear Division, Pratt & Whitney Co. Mem. A.S.M.E.

Presented at a joint meeting of the A.S.M.E. Machine Shop Practice Division and the American Gear Manufacturers Association, Buffalo, N. Y., October 12, 1928.

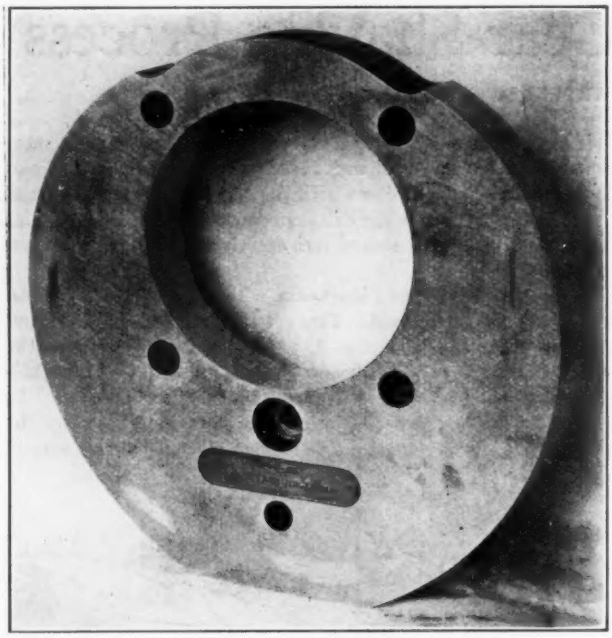


Fig. 5 Master Cam for 18-Tooth, 6-Diametral Pitch, 20-Deg. Gear

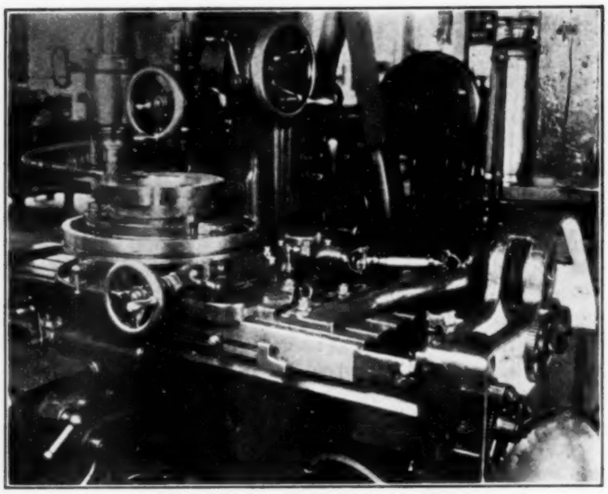


Fig. 6 Cam Milling

edges are parallel to the center line of the gear, a spur gear will be produced. If they are parallel to each other but at an angle to the center line of the gear, a helical gear will be produced. The form of the cutter is the most simple possible with the exception of a point, which is not a very practical cutting tool for gear teeth.

All expense connected with the making of any precision form used in the machine is confined to the master involute cam. Fig. 5 shows a cam for an 18-tooth, 6-diametral pitch, 20-deg. gear. Cams are made of S.A.E. 10115 steel, hardened, seasoned, and ground. They are 12 in. wide across the tangent to the base circle and $1^1/_2$ in. thick. All of the machining operations are conventional with the exception of the milling and grinding of the involute profiles.

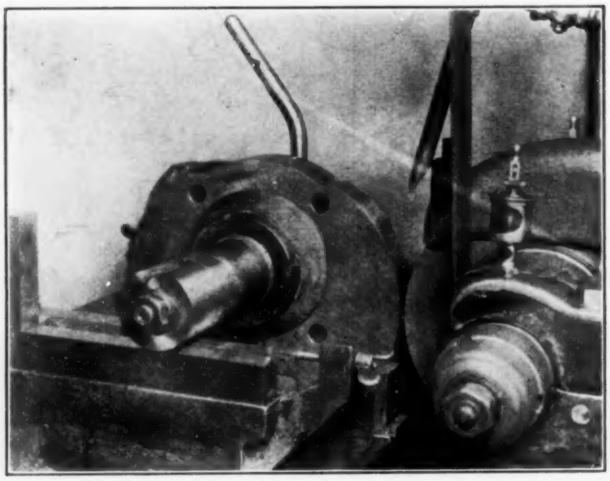


Fig. 7 Cam Grinding

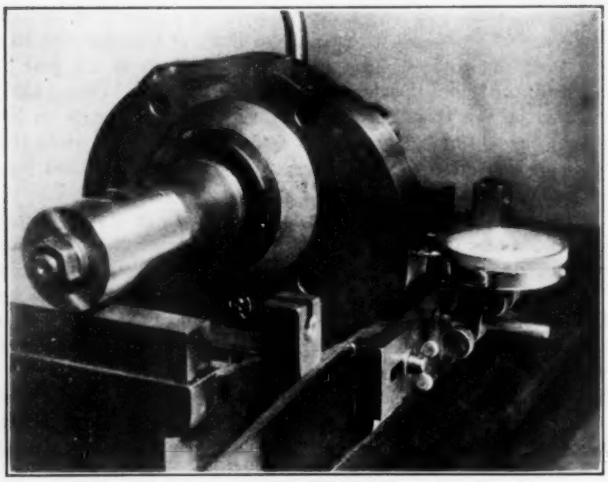


Fig. 8 Cam Inspection

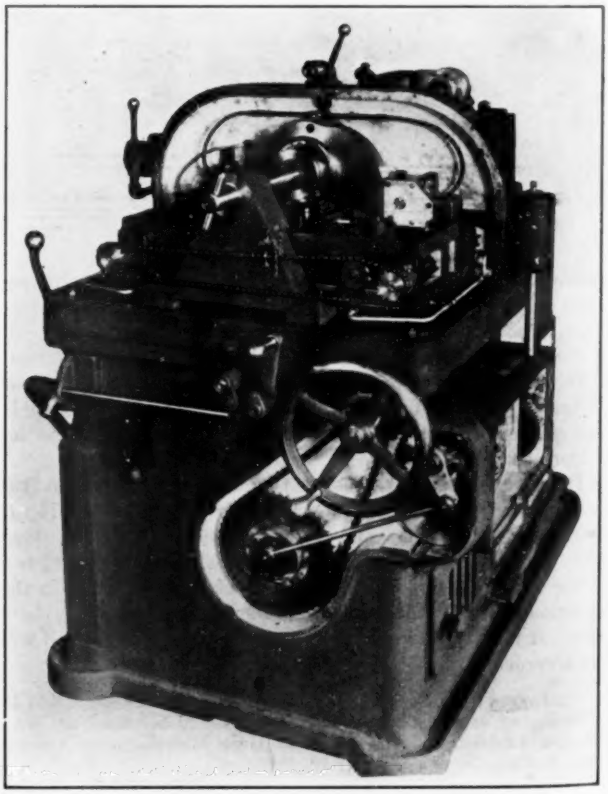


Fig. 9 Front of Machine With Guards Removed

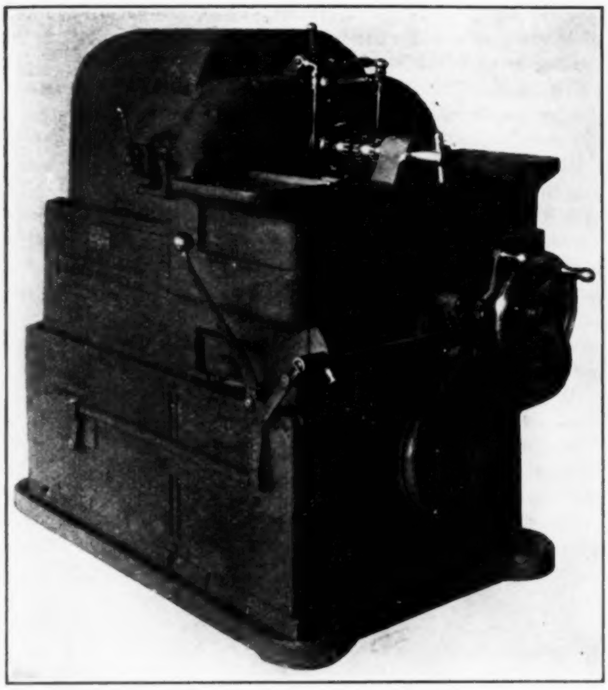


Fig. 10 Front of Complete Machine

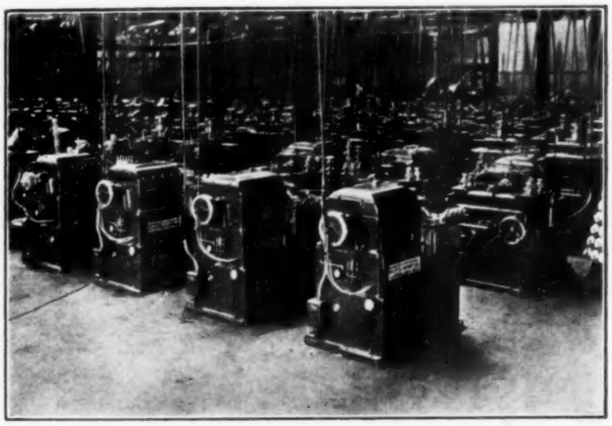


Fig. 11 Machines in Chrysler Plant, Newcastle, Ind.

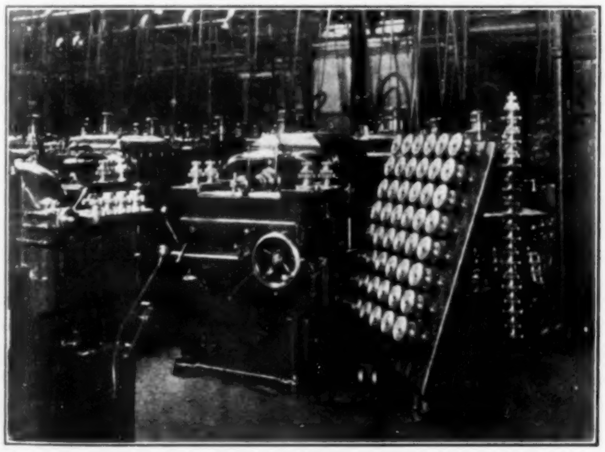


Fig. 12 Machines and Gear Rack

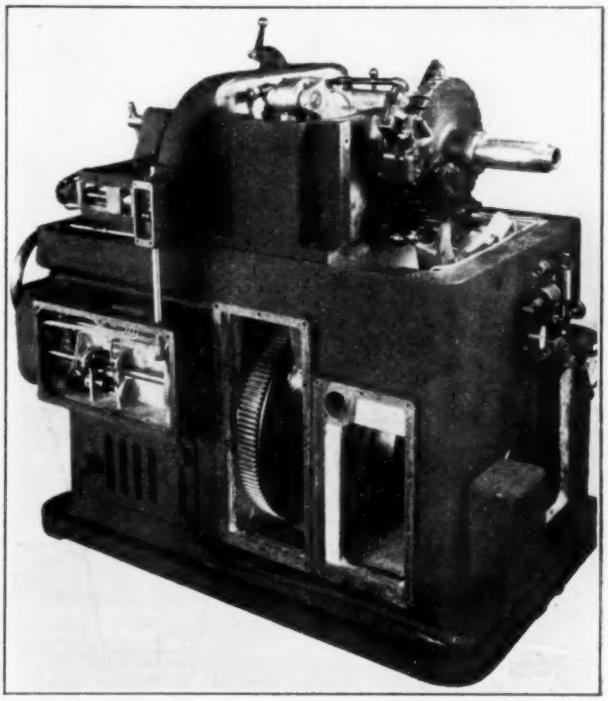


Fig. 14 Rear of Machine With Guards Removed

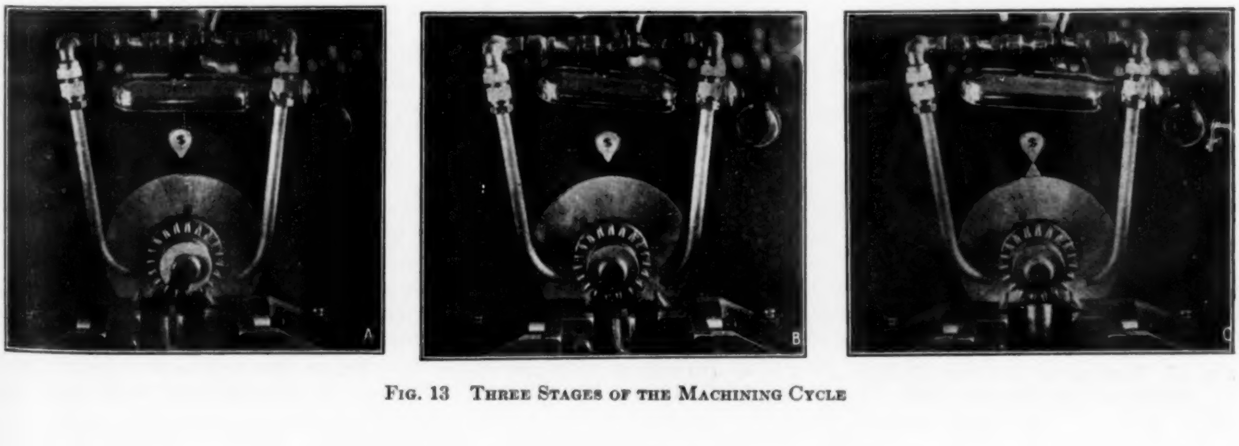


Fig. 13 Three Stages of the Machining Cycle

The cams are milled, as in Fig. 6, on a standard vertical milling machine with a circular milling attachment and a special end bracket arranged for differential change gears. The machine is set up with a milling cutter in the position of the roll in Fig. 1,

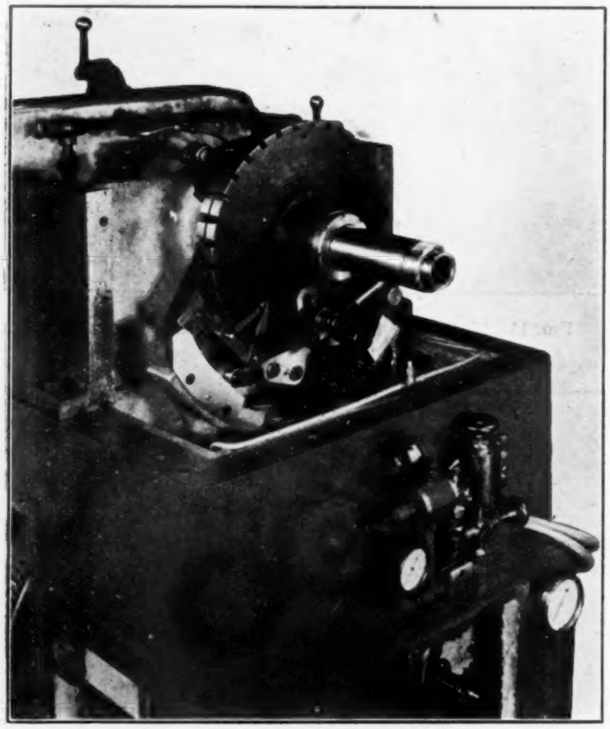


Fig. 15 Close View of the Indexing Mechanism

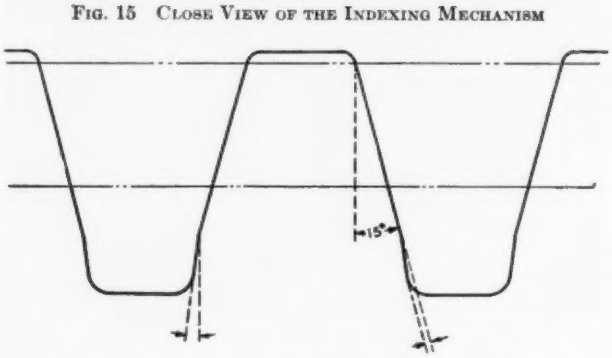



Fig. 16 Normal Section of the Roughing Hob

and the change gearing used is such that the cam makes one complete revolution while the table travels a distance equal to the circumference of the base circle of the gear for which the cam is being made. This being only a roughing operation, a lead is used which is within 0.010 in. of correct for a full revolution of the cam.

The cams are ground, as in Fig. 7, on a standard cylindrical grinding machine fitted with a special generating fixture. The cam is mounted on an arbor having a disk of base-circle diameter on each end, and this assembly is rolled on a steel track, which is the tangent line of Fig. 1 The grinding wheel is placed with its center in the plane of this flat track, and an involute is very accurately generated. The fact that the cam is rolling on a stationary line instead of revolving against a moving line, as in the machine, does not alter the relative motions.

To prevent the disk from slipping on the track, steel bands are used, as in some gear-tooth grinders. The bands are wrapped around the base-circle disk close to but not in contact with the track, the disks at this point being reduced in diameter about the thickness of one band.

The cam is inspected by using a dial indicator, as in Fig. 8, in place of the grinding wheel, its stem being placed in the plane of the track. The bands are removed during the checking operation so that they cannot influence the result.

Fig. 9 is a front view of the machine with the guards removed, showing the master cam and one of the roll housings.

Fig. 10 is a front view of a complete machine set up for a cluster gear, showing all operating controls.

Fig. 11 is a group of seven machines as they appear under actual operating conditions.

Fig. 12 is shown to illustrate the author's conception of the proper way to handle finished gears, with a steel rack for cluster gears. As the machine has been described in detail in *American Machinist* of May 17, 1928, no further description will be given beyond that of the cycle of operations through the shaving of one gear.

In Fig. 13-A the machine is shown in loading position. The gear is placed on the arbor, a C-washer is dropped into a groove in the arbor, the plunger is raised to bring the rack tooth into contact with the gear, centering it, and an air-operated drawbar pulls the arbor back to clamp the gear against the end of a collet in the work spindle. The plunger is dropped and the machine started. The cross-slide carrying the tools moves to the left, the gear turns clockwise, and the right-hand blade cuts, removing all stock in excess of 0.004 in. above finished size, as shown in Fig. 13-B. At the end of the cut the gear and slide reverse direction, and while returning to the starting position the gear is indexed one tooth, relative to the tools, in a clockwise direction. The slide continues on to the right, as shown in Fig. 13-C and the

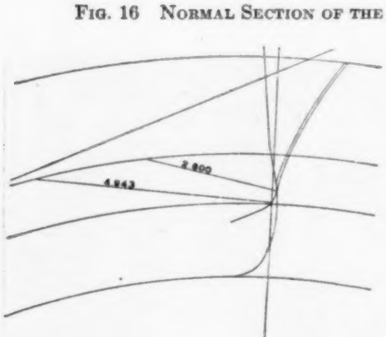


Fig. 17 Diagram of 17-Tooth, 20-Deg. Angle, 20-Deg. Hobbed Gear

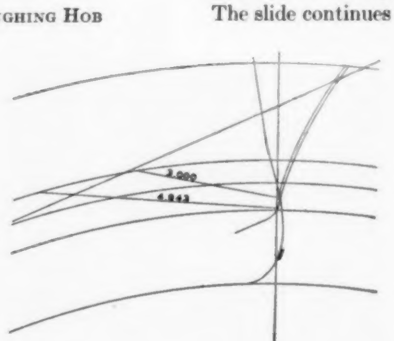


Fig. 18 Diagram of 17-Tooth, 20-Deg. Angle, 15-Deg. Hobbed Gear

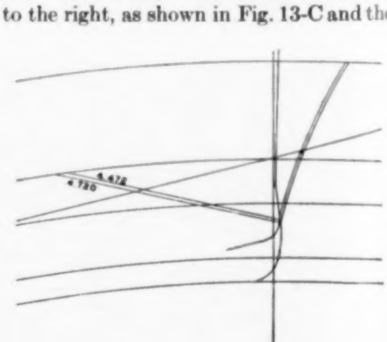


Fig. 19 Diagram of 33-Tooth, 20-Deg. Angle, 15-Deg. Hobbed Gear

left-hand blade cuts. Again reversing directions, the gear and slide return to the central position, and continue on to repeat the cutting cycle. When all the teeth have been cut once, the blades are automatically moved together 0.004 in. and all the

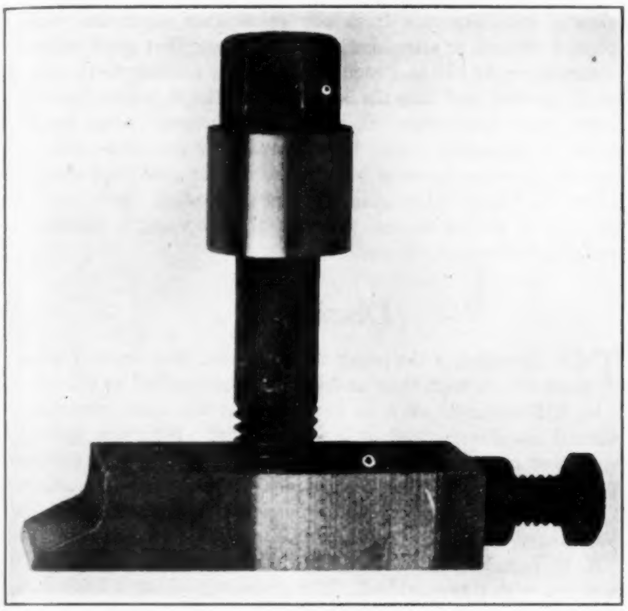


Fig. 20 Cutting Blade

teeth are again cut, 0.002 in. being removed from each side of each tooth. A third and a fourth cut of 0.001 in. each per tooth side are taken, and the machine is automatically stopped. The machine speed is 45 cycles per minute.

Indexing is done by means of a hardened, seasoned, and ground 14-in. notched plate. The location of the plate and index mechanism on the rear end of the spindle is shown in Fig. 14. Fig. 15 is a close-up view of the index mechanism and shows the operating cams more clearly.

It is preferable to rough-cut gears in a hobbing machine, although a gear shaper can and sometimes must be used. This preference is owing entirely to the more favorable shape, for gear shaving, produced at the base of the tooth by the hobbing method. A tooth section of the type of hob used is shown in Fig. 16. To produce a definite undercut in the gear the point of the hob is made thicker than standard by from 0.007 to 0.010 in. on each side. All hobs are made to generate at a pressure angle of 15 deg. as this produces more nearly the desired shape in the undercut curves. For the same reason all gears are cut to full Fellows depth. Otherwise, hobs are made and used as in regular production roughing.

In Fig. 17 is shown the roughed and finished profile of a 17-tooth, 20-deg. pressure-angle gear. It has been hobbed with a thick-point 20-deg. hob, on a 1-diametral pitch gear, to a depth of 2.250 in. instead of the standard 2.157 in. The hob profile is shown just as it is finishing the gear profile. The outer involute profile and clearance curve is the gear as hobbed, and the inner profile is the finish-shaved profile. The involute profile only is shaved, the remainder of the tooth being left as produced by the hob. That part of the involute starting at the base circle has been removed by the hob to give the shaving tools a clearance space into which to cut. The undercut curves are designed to cross the base circle 0.004 to 0.006 in. inside of the finished involute curve. It is found that 0.004 in. is as small as is commercially practical. The line 4.943 is the relative length in inches of the theoretical line of action to the pitch circle of this gear when it is in mesh with a 33-tooth gear on a standard center distance. The line 2.800 is the actual line of action resulting from the removal of the base of the involute.

Fig. 18 is the same 17-tooth gear roughed with a thick-point 15-deg. hob to the same depth. The involute curve is identical with that of the first gear, and the undercut curve crosses the base circle at the same point but at a different angle, which removes less of the involute, resulting in an increase in length of the actual line of action to 3.000 in. Generating at small angles is in this respect more effective the more teeth there are in the gear.

Fig. 19 is the mating 33-tooth gear roughed and finished under the same conditions. The theoretical line of action to the pitch

Fig. 21 Fixture for Setting the Cutting Blade

line is 4.472 in. long and the possible is 4.720 in. The possible being longer than the required, there is no loss of action in this gear from this method of roughing, although there would have been if a 20-deg. hob had been used. The maximum possible number of teeth in contact with this pair of gears is 1.595, and the actual in this case is 1.265. As the loss of action comes from a removal of active profile from the 17-tooth gear close to its base circle, where its use causes a high relative sliding velocity, the loss is not very keenly felt.

Fig. 20 shows one of the shaving tool with its clamping bolt

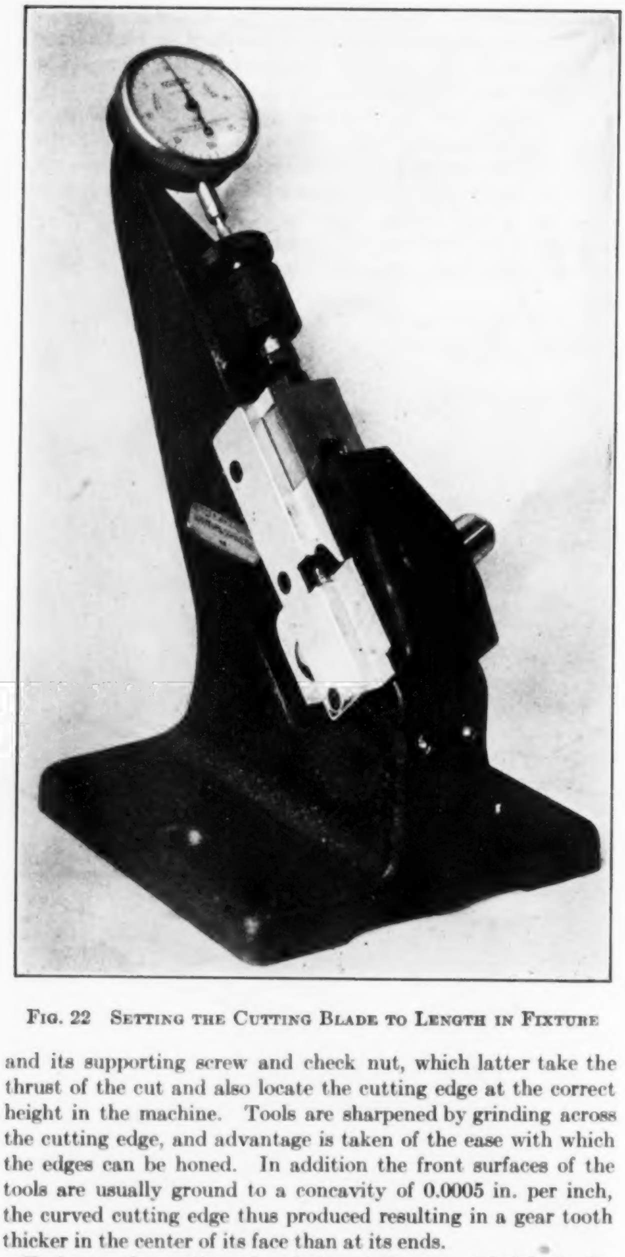


Fig. 22 Setting the Cutting Blade to Length in Fixture

and its supporting screw and check nut, which latter take the thrust of the cut and also locate the cutting edge at the correct height in the machine. Tools are sharpened by grinding across the cutting edge, and advantage is taken of the ease with which the edges can be honed. In addition the front surfaces of the tools are usually ground to a concavity of 0.0005 in. per inch, the curved cutting edge thus produced resulting in a gear tooth thicker in the center of its face than at its ends.

To insure the cutting edges being at the correct height in the machine a fixture is used, as shown in Fig. 21, where the dial indicator is set to zero with a gage which is correct for some particular machine.

In Fig. 22 a tool is shown in the place of the gage, and the supporting screw has been adjusted to bring the indicator to the same zero.

Any carbon tool steel that will hold a keen edge at a hardness of from 63 to 65 on the Rockwell C-scale is satisfactory for cutting tools. The tools will cut from 500 up to 1200 teeth after grinding, depending largely upon the machinability of the gear material. A honing of the cutting edges in the machine will usually give half as many more before the tools need regrinding. The usual cutting compounds are satisfactory, and no unusual heat treatment of the gears before cutting is necessary, although the author prefers the material a little harder than is customary.

The final active profile of a shaved gear is produced by one pass of one cutting edge, and thus is a continuous surface in the direction of roll or slide. Such tool marks as occur from an imperfect cutting edge lie in this direction of roll or slide, and can produce little or no noise.

The point contact of the convexed teeth is very effective in cases of misalignments from any cause that otherwise would produce crossed or edge bearings. All know that gears cannot be commercially cut and mounted with all mating teeth absolutely parallel, and that the bearing cannot be distributed evenly under these conditions. Points of high pressure must be accepted as necessary evils. The convexed or crowned tooth locates the point or zones of high pressure at or near the center of the tooth, the actual bearing, of course, spreading over about 75 per cent of the tooth, but never, if the crowning is sufficient, reaching the ends of the tooth.

## Discussion

The discussion of the paper took the form of a series of questions which, with their answers, are summarized as follows:

H. J. Eberhardt[2] asks, Is the crowning the main advantage claimed for this method or is it accuracy? We claim general consistent accuracy and a character of finish—namely, cutting in the direction of roll—which is ideal for a gear-tooth surface. The crowning is an incidental possibility, of which we take advantage.

A. H. Lane[3] asks, What is the widest tooth that you are able to shape with this machine? The present machine is limited to 2 in., but the limit depends upon the power which can be put into such a machine. We are not using the machine at present on bronze gears or other nonferrous gears, although bronze gears were cut on the original experimental machines. In general, the machine follows the characteristics of other gear-cutting machines in that the softer or more machinable materials can be cut with a better finish and a higher degree of accuracy. The softer metals will probably be cut with fewer cuts, although a cut of 0.002 in. is all that can be taken at one time successfully.

Chester B. Hamilton[4] asks, Are there any modifications, entries, etc., obtainable this way, and when we shape these gears do we find it necessary to shave an entry modification. We have found no modification of the involute required. A correction for hardening distortion is made by cutting the gears in the green, so that the normal pitch or spacing of the involutes on the base circles is made slightly longer than standard on the driving gears. This correction in general amounts to from 0.0001 to 0.0004 in. The heat treating of these gears causes a change in the normal pitch which makes them approximately correct.

I am asked how we finish hardened gears. Hardened gears are not being shaved in these machines at present, although we have shaved chrome-vanadium steels up to a hardness of 75 scleroscope. It is entirely practicable so far as the machine is concerned, but we have not found any cutting steels which would stand up to this work.

Nikola Trbojevich[5] says that he does not understand how we cut helical gears if the base circle is below the root diameter. He is correct. We cannot shave them under these conditions.

A member states that an internal gear can be shaved by making a hardened pinion and having each tooth a different height, and that General Barnes has a patent in which he shows a section of this type of gear. He is not cutting it at present, however.

[2] Newark Gear Cutting Machines Co., Newark, N. J. Mem. A.S.M.E.

[3] Industrial Planning Corp., Buffalo, N. Y. Mem. A.S.M.E.

[4] Hamilton Gear and Machine Co., Toronto, Ontario, Canada. Mem. A.S.M.E.

[5] Timken-Detroit Axle Co.

# Some Practices in the Use of Machine Tools in the Electrical Industry

By J. R. Weaver,[1] East Pittsburgh, Pa.

This subject of machine tools and their use in manufacture covers quite a varied problem, and the author is going to deal with it in a general way from the experience obtained in the manufacture of electrical apparatus. Of course the question of using standard machine tools or special machine tools depends entirely upon the activity of the apparatus being manufactured. Standardization will undoubtedly increase this activity, and it is believed that the electrical manufacturers are standardizing as rapidly as is possible. There is still much to be done, and most of the equipment that we install must be suited for general conditions and yet, at the same time, it must be adapted to high production.

There are several ways in which high production or increased activity can be obtained from a standard tool. One of them is adapting special fixtures that will allow multiple or continuous cutting. Where the work does not warrant a special high-production or single-purpose machine, a standard machine equipped with a special multiple holding fixture such as a rotary fixture on a standard milling machine, a rotary table on a drill press, or two separate fixtures on a milling-machine table, can be used. Any one of these methods permits loading while machining is being done, thereby eliminating lost time on the part of the operator.

Owing to the necessity of meeting special requirements of the customer, work in the electrical business is so diversified that standard machines with special holding fixtures are used extensively. Another method is to arrange several machines in sequence operated by one operator, which may not increase the production, but will reduce the cost because one operator is operating several machines. We are using both methods with very good success, and in several cases we have as many as seven or eight machine tools operated by one operator, depending upon the time element in each operation. In our die-making department, where we are installing measured day work, which is an incentive payment plan, one operator is handling two shapers. We also have one operator on two standard milling machines without any special fixtures. Semi-automatic and automatic machines are usually grouped so that one operator can handle several machines. With equipment having controlled feeds and rapid power traverse, it is surprising how well machines of this type adapt themselves to multiple operations.

Wherever sufficient economies can be realized, special machines are installed which are purchased from machine-tool builders or designed and built by ourselves. We also have certain operations that cannot be done on machines that are on the market, and these we have to build ourselves.

Although we believe that fixtures should be designed and built by the manufacturer of the machine tool and installed on the machine while it is being built, we find it quite inconvenient in that it extends the time of delivery of the machine. Owing to the amount of correspondence which takes place and the misunderstandings that oftentimes arise, it is usually advisable to build our own fixtures. However, we try to take advantage of machine-tool builders' experience.

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Presented at the Second National Meeting of the A.S.M.E. Machine Shop Practice Division, Cincinnati, Ohio, September 24 to 27, 1928.

### Comparing Planing and Milling

The subject of comparing various operations and the methods of performing them is quite interesting in our industry, and the author wishes to mention and to describe briefly several of them. We have been carrying on various studies of planing versus milling on our products, expecially on our larger work. We find on some work, especially on form surfaces, that planing is much more economical than milling for the reason that we can maintain our form and size with the least expenditure. It must be admitted that milling cutters, if of any size at all, are very expensive and that it is necessary to have several sets owing to the fact that the machines must be kept operating. When only a single set of cutters is available, the machine is idle while they are being ground, but with a planer and a simple planer tool the investment is not so great and the time required to perform the operation is not very much longer, if any. However, on flat surfacing especially where there are a lot of pads to be finished, etc., the author believes the milling machine is better adapted than the planer.

We do considerable surface grinding on castings, and we find this to be a very economical way of finishing surfaces providing there is not more than $^1/_4$ in. of metal allowed for finish. This includes both cast-iron and cast-steel castings, and I was very much surprised to learn recently that one of our 54-in. machines removed $1^1/_4$ in. of stock from the base of a pedestal at one pass. This of course was an accident, but apparently no damage was done. However, I do not know whether this could be repeated with the same results.

We are going quite extensively into welded fabricated steel construction work on our apparatus, which is reducing our machining time considerably, and the thought occurs that it may be possible, to some extent at least, to apply the same construction to machine tools. This is just a thought, and the author is not prepared to go into details of design. It seems that in certain instances fabricated construction could be used to advantage. In the case of a lathe a fabricated bed could be made, and if cast iron ways are desired, they could be attached to the steel construction and still make a lathe bed that would be just as good as if all were of cast iron and for less money.

We have gone into this construction on our jigs and fixtures very extensively and find that we have not only reduced costs but have shown an advance in delivery of three weeks on each jig. This is due to the fact that it takes about three weeks to obtain a casting, including the time that it takes to make the pattern.

Fabricated parts can of course be bent or shaped very closely to the final dimensions, so that a very small amount of machining is required, and in quite a number of cases none at all. If this practice were adopted, it would probably mean that it would not be necessary to build machines as heavy and rugged as in cases where steel castings are used.

We have been experimenting with some special alloy steel on which we have been able to increase our cutting speeds and certain operations as much as 250 per cent and still obtain good results. This special alloy steel combined with fabricated steel construction would mean that machine tools ought to be built for and run at a much higher speed. Machines of this type would not be required to take as heavy cuts as is necessary on castings. This special alloy steel mentioned is just in the experimental stage, and

although the results up to the present time are promising, we are not prepared to make definite recommendations.

We have also been experimenting with the chromium plating of cutting tools quite extensively and on materials other than metals we have had very good success with this process, but when cutting steel and cast iron we find that the plating chips off at the cutting edge. The cutting tool gives no better results than a standard cutting tool.

### Die Casting and Hot Pressing Employed

The manufacture of apparatus from alloys of aluminum, copper, brass, zinc, etc., introduces die casting and hot pressing, which reduce machining quite considerably. In most cases machining is eliminated entirely. We have set up three processes for handling these alloys, grouped as follows:

*Die Casting.* By this method we make castings from zinc-base alloys and aluminum. This is done under pressure in a metal die, with the result that the casting does not usually require any machining except drilling or tapping, as the case may be. High activity is necessary for the use of this process as it requires a metal die and is rather expensive even though the operation of casting is very rapid.

*Permanent Molding.* This method is used for making castings from iron aluminum bronze, or aluminum alloy. This is somewhat similar to die casting except that no pressure is used and that molds are set in machines designed for opening and closing them quickly and that the pressure for the casting is obtained from the size of the gate and header. This has proved very satisfactory, and owing to the fact that steel molds are used in this operation, the castings are very close to the finished dimensions.

*Hot Pressing.* This process is used on castings or forgings that are designed from forged brass or copper. The types of presses used for the operation are drop hammers, screw presses, crank presses, and hydraulic presses. A very dense forging is obtained from this process, and it is very close to dimensions, so that the least amount of machining is necessary. One objectionable feature of this method is that, when using a press or a drop hammer, flash dies must be used, and on small forgings the flash is often greater than the piece itself. This naturally increases the losses due to excessive material and increases the cost of forging. We have been working for some time with closed dies for some of our work, eliminating practically all flash. We are having very good success with this type of die, depending of course on the size and shape of the piece that we wish to forge. Where the forging required is thin, we find that the flash die is necessary, but where the forging has a considerable amount of body to it, a closed die can be made, eliminating practically all flash.

These various processes, it is understood, are used to some extent on cast iron and steel, but in our experience we have only applied them to the alloys mentioned, with good results in eliminating machine work.

There is no question but all manufacturers are reducing as far as possible the amount of finish on their castings and forgings. If this continues, it looks as though at some time in the future the equipment will be of lighter construction, of high speed, and easily handled, depending on the development of cutting tools. With the new designs in machine-tool equipment it looks as though the manufacturers must look for savings in other directions rather than just on machine tools. It is hard to predict just how much improvement can be obtained from the redesigning of machine-tool equipment, but it appears as though they have gone as far as it seems possible.

## Discussion

Erik Oberg.[2] A good deal is being done in cutting-tool experiments, both in this country and abroad. A new type of cutting tool has been brought out in England and Germany and in this country. Undoubtedly, this will affect the machine-tool business, ultimately, to a great extent. A new lathe has been brought out in Germany that has unusual power and speed. It is claimed that this new lathe is able to take heavy cuts on forgings at 500 ft. per min. That is so tremendous compared with anything done hitherto that, if correct, it cannot but affect the machine-tool business.

E. F. Du Brul.[3] Concerning the point brought out by Mr. Oberg, many of us remember the revolution which came in the machine-tool business by the discovery of high-speed steel. When Mr. Taylor brought some chips to the meeting of the A.S.M.E. at Cincinnati in 1901 or 1902, we were all astonished at their size. Mr. Oberg has reported a tool cutting forgings at the rate of 500 ft. per min. It is purely a question of putting power behind a cutting tool, if it has been found that a material can be cut that fast. Mechanical ingenuity is not so limited but that enough power can be put behind the tool to get from it all that it can do. That means a revolution in machine-tool design, just as high-speed steel created a revolution nearly five years ago.

Die casting is another revolutionary process. There has been interesting work done around Bridgeport, Conn., on a principle, evolved by a Frenchman, of casting steel by centrifugal force. The centrifugal force acts to condense any material poured in the mold. Such a casting has much greater tensile strength than castings made without the centrifugal pressure. The developers claim to have demonstrated that they can cast any material in these molds and to quite large dimensions. This means a substitution of steel parts for iron. Of course the new parts will create a new demand for machine tools of some sort. These revolutionary processes and materials throw the doors of opportunity wide open to those who are able to enter. These are the user companies that have the money to buy the new machines, and the builders who have the money or credit to design the new machines that will take the high-speed cuts. The possibilities are something tremendous. It will do no good to complain about this condition; the thing to do is to recognize its possibilities and do everything to push it ahead and get the big market which it opens.

[2] Editor, *Machinery*, New York, N. Y. Mem. A.S.M.E.

[3] General Manager, National Machine Tool Builders Association, Cincinnati, Ohio. Assoc. A.S.M.E.

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# Progress in Oil- and Gas-Power Engineering

## Contributed by the Oil and Gas Power Division

Executive Committee: E. J. Kates, *Chairman*, L. H. Morrison, *Secretary*, J. W. Morton, C. M. Manly, and H. A. Pratt

WHILE the preceding two or three years of oil-engine history were characterized by increasing compression pressures, 1927 has marked the beginning of what may prove to be a long struggle for higher speeds. The pressure increases that have taken place in recent years in several manufacturers' products were effected not so much with the aim for higher output as for the sake of convenience in operation. Cold starting was the object, occasionally also the elimination of water injection. As a result of this tendency, the low-compression or semi-Diesel engine which a few years ago represented the majority of oil-engine horsepower manufactured almost disappeared from the picture in 1927.

The present trend is unmistakably toward higher speed in order to obtain more power per pound of engine weight. The incentive is the conquest of the mobile field for the heavy-oil engine. The distinction of having attained the greatest recent progress therein belongs to the Diesel locomotive (4).[1]

### Diesel Locomotives

From a timid beginning a few years ago, we have at present an established type of switching locomotive in the United States, used by at least ten railroads and several industrial companies with satisfaction and effecting considerable saving (47). Orders have been placed for at least three main-line locomotives by at least two railroads (24), and their construction is nearly completed. Two destined for the New York Central are being built in this country and have electric transmissions. One of them will be equipped with a 6-cylinder, 750-hp., 500-r.p.m. Ingersoll-Rand solid-injection engine, the other with a 12-cylinder, 800-hp., 325-r.p.m. McIntosh & Seymour air-injection engine. The one to be delivered to the Boston and Maine Railroad is being built by the Krupp Company, Essen, Germany. It is to be equipped with a 6-cylinder, 1300-hp., 470-r.p.m. Krupp solid-injection engine, and has gear transmission with magnetic clutches.

In Europe not less than 19 companies are engaged in the construction of Diesel-engine locomotives and rail cars. Several of them have achieved notable commercial success (4). At least nine locomotives of the Canadian National Railways have been fitted with Beardmore engines (33) of 400 hp., 750 r.p.m., using electric transmission. Some of them have been in use for over two years and have exceeded a mileage of 100,000 without a refit. The British Company is now building 12-in. × 12-in., 12-cylinder V-type engines developing 1200 b.hp. at 750 r.p.m. with an overload capacity of 1500 b.hp. at 900 r.p.m. The complete engine weighs 22,000 lb. or about 18 lb. per hp. Such an extremely low weight for this type of engine is a truly remarkable engineering achievement. Two of these engines giving a total of 3000 hp. are now being built in one large locomotive, giving a tractive effort of 100,000 lb. and hauling a 750-ton passenger train at 70 miles per hour.

Engines built by a number of German Companies (M.A.N., Deutz, Benz, Krupp), and also several Italian (Fiat and Tosi) and Swiss (Sulzer) companies have been successfully installed recently in locomotives and connected with electric, hydraulic, pneumatic, and mechanical transmissions of a great variety (15). Perhaps the most interesting foreign development is the direct-driven Kitson-Still locomotive (26), the double-acting engine pistons of which are driven by the internal combustion of oil on one side and steam on the other: the steam is generated by the heat of the exhaust gases. It is not so much the high thermal efficiency of this combination which commends it for locomotive use, as it is the flexibility which the steam provides (and which the internal-combustion engine lacks) and makes the cumbersome transmission unnecessary. The French Schneider works (4) is also building a locomotive on this principle and the trials on both are awaited with keen interest.

Out of at least 17 different systems of transmissions which are being tried for oil-engine locomotives, only the electric drive has proved itself beyond doubt so far, but the developers of the other systems are busy and it cannot be predicted which one will be ahead 12 months from now. In spite of the considerably higher first costs of the oil-electrics, operating experience gained in the last two years (45) shows that the Diesel locomotive is more economical to operate than the steam locomotive.

### Automotive Diesels

For automotive application still higher speeds and lower weights are required. Last year's progress in this field includes the new Junkers (23), Benz (3), Dorner (29), and the improved M.A.N. (23) and Peugeot (9) truck engines, scores of which have already been installed and sold in Europe. These engines have crankshaft speeds of 1000 r.p.m. and over, and weights of around 20 lb. per hp. A M.A.N. three-ton truck with a modified piston (Acro patent) and injection system is being demonstrated here by the Robert Bosch Company (25), Long Island City. Its fuel economy is remarkable (about 0.6 cent per mile), while its flexibility and ease of handling leave nothing to be desired.

Among the other recent mobile and semi-mobile applications, the Caterpillar tractor, engined with a 75-hp., 650-r.p.m. Atlas Imperial Diesel (39), may be mentioned as a promising American development. High-speed engines recently developed by the Fairbanks, Morse & Company (40) [800 r.p.m., 12$^1/_2$ hp. per cylinder], Foos Gas Engine Company (10) [700 r.p.m., 80 hp. per cylinder], Cummins Engine Co. (42) [600 r.p.m., 12.5 hp. per cylinder], Bessemer Gas Engine Co. (43) and Hill Diesel Engine Co. (28) open the field for still wider use of the oil engine for dredging, excavating, road construction, small boats, and rail cars. The Treiber Company together with the American Brown Boveri Corporation are developing high-power light-weight engines, one of them being of the 9-cylinder radial type.

Besides those already mentioned at least six American companies, mostly manufacturers of gasoline engines, are, it is rumored, engaged in developing automotive oil engines, and we may be able to report definite accomplishments next year.

For aircraft application (2) the weight becomes of predominant importance. Although its higher thermal efficiency and reduced fire danger are in favor of the heavy-oil compression-ignition engine and its development is being pushed by the American and English governments, its use cannot become general before the engine weights are brought down to figures which compare favorably with those of gasoline engines. It may be added, however, that no principal reason is known why engines working

[1] Figures in parentheses refer to references listed in the Bibliography.

on the Diesel principle cannot equal or excel carburetor engines in power output per pound of engine weight. On this continent the Attendu engine (6) [3.6 lb. per b.hp.] and the Sperry supercharged engine (5) represent promising experiments. Abroad, Junkers is planning on fitting his airplanes with his two-cycle, opposed-piston-type engines, and one of the new British dirigibles will be fitted with Beardmore engines, if rumor is correct.

### Giant Diesels

Looking at the other end of the picture, the progress made in high-powered Diesels is no less gratifying. Shipbuilders are the best customers for large Diesels. The increased popularity of the Diesel with ship owners is shown by Lloyd's figures. On September 30, 1,163,630 i.hp. of marine oil engines were under construction against 568,969 i.hp. of reciprocating steam engines and 309,900 hp. of turbines. Oil-engine tonnage increased to $52^1/_2$ per cent from $19^1/_2$ per cent four years ago. From a spectacular standpoint the most outstanding installations were single engines of the Doxford opposed-piston airless-injection type, 5000 screw hp. in four cylinders, in two single-screw vessels; and single engines of the Burmeister & Wain double-acting four-cycle type, 9000 screw hp. in eight cylinders, in three double-screw vessels. The latest set of these, installed in the *Saturnia* (44), is supercharged with two electrically driven turbo-blowers, which increases the output of each engine to 10,000 screw hp. The *Augustus* (35), the largest motorship in the world, 33,000 gross tons, equipped with four M.A.N. engines, 700 screw hp. each, has made her maiden voyage this November. The largest cylinder output ever attained was obtained this year from a Sulzer experimental one-cylinder engine, delivering 2900 i.hp. (46).

In this country several more Shipping Board vessels were converted into motorships (10). Nine main and 27 auxiliary engines were tested and delivered by six companies during the last fiscal year. Contracts have been awarded recently for the construction of eight more engines of about 4000 hp. to four different companies. Two are two-cycle single-acting, four are two-cycle double-acting, and two are four-cycle double-acting. The contracts are on the basis of $74 per b.hp., including scavenging blowers.

In the stationary field more high-powered Diesels are being installed in electric central stations. In the Commerce Mining and Royalty Plant in Oklahoma, three Nordberg two-cycle engines have been installed totaling 6750 b.hp. The favorable experience with the 15,000-hp. Diesel engine installed in 1926 for the Hamburg Electrical Works induced a Berlin electric-power company to place orders with M.A.N. for two 10-cylinder 12,000-hp. engines, 215 r.p.m. (21.3 ft. per sec. piston speed) to be used as stand-bys. America's largest Diesel power plant, the Panama Canal plant at Miraflores (27), consisting of three single-acting two cycle Nordberg engines and having a peak-load capacity of 12,375 hp., has been completed this year and serves a similar purpose.

### Diesels for Peak Power

It is readily admitted that unless favored by particular local conditions, the Diesel engine cannot compete with steam and water turbines for large power generation. On the other hand, both calculations and experience have shown convincingly that their combination with steam and water power for peak loads and emergencies offers decided economical advantages (11). For short-period operations, the higher fuel cost of the Diesel is more than offset by its lower interest on first cost compared with water power and by its lower cost of keeping it prepared for emergency, compared with steam power. The water-power central station at Bremen installed two 3000-hp. Sulzer Diesel units to cooperate with water turbines. The 4500-hp. Diesel set of the Société des Forces Motrices du Refrain operates satisfactorily together with water and steam turbines. The possibilities of the Diesel engine for central stations are not yet fully realized (19).

### Continuous Production

In medium-size engines, so far as design is concerned, no striking progress made in the last twelve months can be recorded. Many of the new models recently introduced in this country are licensed by foreign patent owners. Among the recent changes the popular adoption of the box frame and the improvement of the exterior appearance of the engines are most noticeable.

On the other hand, more and more engineering skill is being applied to production. Refined finishing methods are finding their way into Diesel machine-shop practice. Grinding and honing of cylinders, broaching of wristpin bushings, and lapping of spray needles, pump plungers, and even valve seats are used with success.

Larger builders have made progressive steps toward continuous production of engine units, using interchangeable parts, conveyors, and systemized material-handling methods.

The manufacture of small- and medium-size gas engines has lost its significance since the advent of the gasoline and Diesel-type engines. Where industrial gas is available as a by-product of blast-furnace and steel-mill operations, large gas engines are still most economical generators of power. The Allis-Chalmers Company is building gas engines in units up to 4000-hp.

### Accessories

Many good accessories which have recently been placed on the market, either increase the usefulness of oil engines or relieve their builders from making such items themselves. Air and oil filters, centrifuges for lubricating and fuel oil, charging and scavenging blowers, distant-reading cooling-water and exhaust thermometers, and high-speed indicators are only a few of a worthy list. Fuel pumps and spray nozzles were not considered accessories until recently, yet at least one foreign and one American manufacturer are contemplating manufacturing these delicate engine parts and selling them to the oil-engine builders. Such a specialization in manufacture will probably further reduce the cost and increase the utility of the oil engine.

### Trend of Design

While accurate figures are not easily obtainable, the trend is unmistakably toward hydraulic (solid) injection. Out of the total horsepower of stationary engines built in this country, 53 per cent was of the airless-injection type in 1924, 56 per cent in 1925, and 58 per cent in 1926, excluding the low-compression engines (3). In Germany and England this trend is still more pronounced. Hydraulic injection is not yet generally applied to the largest sizes, but Doxford and Burmeister & Wain have recently built airless-injection engines with 1250- and 1125-b.hp. cylinder capacities, respectively. It is being tried experimentally both on the Sulzer double-acting engine and on the Harland-B.W. design.

The struggle between two-cycle and four-cycle is still undecided. The respective figures for American stationary engines for the last three years are as follows:

| | 1924 | 1925 | 1926 (Estimated) | |
|---|---|---|---|---|
| Two-cycle...... | 42 | 51 | 49 | Per cent of total horsepower |
| Four-cycle..... | 58 | 49 | 51 | |

In marine application the two-cycle seems to gain over the four-cycle, while for locomotives the opposite is the case.

The most spectacular advance, however, has been made by the double-acting principle. Not long ago double-acting engines were considered experimental, but now there are six different makes of double-acting engines in operation at sea and five more in a very advanced degree of development. Perhaps one reason why shipowners favor the double-acting two-cycle design is because it resembles most the familiar reciprocating steam engine.

As regards construction, a trend toward more rigid frames is noticeable. The A-frame is being displaced by the box frame with individual or cast-in-block cylinders. Rigid connections between the individual cylinders or cylinder heads frequently serve the same purpose. The reduced vibration and bearing wear achieved with the rigid construction justify the additional expense.

The chain drive of the camshaft, introduced not long ago, has won further adherents.

The use of aluminum and alloys for pistons is being tried with promising results. The use of high-grade materials for other engine parts together with refined finishing methods is also progressing, especially with high-speed machinery.

Efforts are being made to secure higher mean effective pressures for two-cycle engines. Crankcase scavenging is slowly losing ground, while the use of blowers is gaining for both charging two-cycle and supercharging four-cycle engines. At present the employment of blowers is restricted to large engines, but their introduction for medium and small engines is predicted.

In the controversy over direct spray injection as against a precombustion chamber, both parties are holding their ground, and no gain for either can be recorded.

New injection systems are still being introduced and a perplexing number of varieties are already available. Some of those recently developed take a middle place between the direct pump injection and the accumulator (common rail) system, by accumulating with each pump stroke only fuel enough for one injection, and using a mechanically operated valve for timing the injection.

The possibility of controlling turbulence by directing the intake air has been firmly established by the Hesselman, Krupp, Junkers, and Langley Field experiments, proving conclusively that the rotation of the air is not killed by the compression. German designers have already taken advantage of this fact, apparently with good results.

By supercharging with the Büchi system (45) using exhaust turbines for driving the blowers, the Swiss Locomotive Works has succeeded in increasing the rating of a four-cycle engine by not less than 50 per cent without any increase of the exhaust temperature, if reports are reliable.

## Research

The oil-spray investigation of the National Advisory Committee for Aeronautics at Langley Field is yielding results. The subjects investigated lately and reported upon by the committee are: An investigation of the coefficients of discharge of liquids through small, round orifices, by W. F. Joachim (48); some factors affecting the reproducibility of penetration and the cut-off of oil sprays for fuel injection, by E. G. Beardsley (49); and factors in the design of centrifugal-type injection valves for oil engines, by W. F. Joachim and E. G. Beardsley (50). Experiments with various compression chamber designs (31) and novel injection nozzles are in progress, and favorable reports will probably soon follow.

As a result of the oil-spray research at the Pennsylvania State College (34) the development of an electric recording multi-diaphragm-type oil-pressure indicator has been reported (39), by which oil-pressure fluctuations of several thousand pounds taking place in a few thousandths of a second have been recorded and time-pressure diagrams taken.

Some experiments on oil jets and their ignition have been carried out by A. L. Byrd (17) at the University of Cambridge, using square orifices for injection of the fuel.

In Germany, elaborate investigations have been conducted for the determination of the globule sizes of atomized oil sprays. Kuehn counted the number of globules received on a smoked-glass plate, Sauter (21) used light absorption and also an electric charging method to determine the average size of the particles, and Wöltjen (2) injected the fuel into a non-miscible liquid of the same density and photographed the drops thus obtained.

The ignition of oil sprays has been investigated by Neumann (13) and Sass (41). The old dispute whether or not evaporation is essential for the ignition of liquid fuel, seems to be settled in favor of the latter.

Interesting temperature measurements on an Acro engine have been made by Stribeck (32). The interpretation of his results, however, is still the subject of lively discussions.

The Marine Oil Engine Trials of the Institution of Mechanical Engineers (20) have cleared in five reports many doubtful points in regard to the adaptability of the oil engine to ship propulsion.

The scavenging of two-cycle engines has received additional attention. Tests on a crankcase-scavenging engine have been reported by Holm (36). Many others are being kept secret.

Most of the investigations mentioned are being continued and further results are expected in the near future. The "secondary discharges" of automatic nozzles pointed out first by Eichelberg (14) and experimentally observed by Beardsley may clear up the problem of the so-called "after dribbling."

Investigations in the direction of increasing the speed and the m.e.p. are being quietly carried out in manufacturers' laboratories.

As to fuel economy, 0.354 lb. per b.hp-hr. has been reached (30), and 0.3 lb. per b.hp-hr. is being predicted by an English authority.

Of the researches in allied fields, the production of synthetic fuels and the nitration process invented by the firm of Krupp, by which steel on the surface is made as hard as quartz and not deformed, may have important consequences on the development of oil engines.

## Activities of the Industry

Oil-engine business in general was not particularly brisk during the last twelve months. Production was kept up fairly well, but the profit sheets show a decline. Yet more and more capital is flowing into the industry due to the increased interest in Diesel engines. The Conversion Program of the Shipping Board calling for an expenditure of $25,000,000 gave a healthy impetus to the industry. Out of this sum $2,783,256 was spent in the fiscal year preceding June 30, 1927, and $2,290,300 worth of engines has been contracted since.

The Oil Power Week, held April 18–23 under the auspices of the A.S.M.E. and six other engineering societies, focused general attention on the production of power by the use of oil, by means of simultaneous meetings, discussions, and publicity. One hundred and six meetings were held throughout the country, and many valuable papers presented. The $100 Rudolph Diesel prize was awarded to W. F. Joachim of Langley Field Memorial Aeronautical Laboratory for his paper entitled "Oil Spray Investigations of the National Advisory Committee for Aeronautics" which was presented at the Oil Power Conference at The Pennsylvania State College, State College, Pa., and will be published later in the Oil and Gas Power Division's Quarterly. [See Trans. A.S.M.E., vol 50 (1928), no. 1, paper no. OGP-50-6.]

## The Needs of the Industry

This report would be incomplete if it ignored certain handicaps the industry is confronting. Diagnosing a disease always

helps to find the proper cure. It would perhaps be futile to deny that our oil-engine industry is not taking the place that it rightfully deserves. On September 30 out of 1,163,630 i.hp. of marine oil engines under construction in the world, only 13,090 were being built in the United States, compared with 365,440 in Great Britain, 244,370 in Germany, and 157,850 in Italy. It is true also that fewer ships were under construction in this country than in those mentioned, but certainly not less than in Switzerland. Yet Switzerland is building $6^1/_2$ times as many (85,000 i.hp.) marine Diesels as we are. As stated before, $52^1/_2$ per cent of the merchant vessels under construction in the world are motorships, but only 14.4 per cent of the American tonnage. With 76 per cent of the world's petroleum produced in this country, it is very safe to say that less than 10 per cent of the oil engines are made here. The 1926 exports in Diesel and semi-Diesel engines amounted to less than three million dollars, while in metal-working machinery it exceeded eighteen million. For other countries the proportion would be more nearly the reverse.

Production costs are high, selling costs are high, the competition of the electric-power companies is destructive, the power users have not sufficient confidence in oil engines—these are the explanations most frequently offered, but none of them is of such a nature that the manufacturers cannot do anything about it. A closer cooperation between the engine builders would accomplish a great deal in the direction of reducing selling costs and enlarging the market by an intelligent and systematic education of the power users as to the economic possibilities of the oil engine. Research, preferably cooperative research, would help to produce more efficient engines. We have heard from D. R. Pye, the English authority, just a few days ago that "a great deal of further research with the jerk pump is needed to place the designer in a position to know what are the characteristics of the jet he is producing." The cut-and-try method which is being practiced now is the most expensive of all, and will continue to be as long as we are in the dark as to the fundamentals.

Reduction in production costs could be achieved by specialization and adoption of modern production methods. The "part maker," a familiar figure in the automobile industry, has a justified place in the oil-engine industry as well. Few oil-engine builders are equipped to produce high-quality pistons, fuel pumps, and injection nozzles economically. Making fewer parts in larger quantities, we shall be able to adopt methods of quantity production: interchangeability, the use of jigs, fixtures and rapid-inspection gages; adopt continuous synchronized production, and do away with chalk and file and large-part storage.

The industry needs more trained men. In connection with oil engines, more than in most other fields, we formerly depended on men trained abroad. With immigration largely cut off, a shortage is being felt. A greater supply of skilled oil-engine operators would undoubtedly improve the market. Each competent operator helps to turn the sentiment in favor of the Diesel engine and is undoing some of the wrong done in the past by the many incompetent Diesel operators. We need more factory men skilled in erecting Diesel engines and machining delicate engine parts. We need more field service men able to diagnose troubles and give proper service to customers. We need more engineers trained in the design and developments of Diesel engines, men with sufficient theoretical background and some familiarity with the work that has already been done on the subject. Too often we see costly duplication of mistakes that could easily be avoided. Our technical schools do not give proportionate attention to the teaching of internal-combustion engines. If the oil-engine manufacturers would fall in line with the others in cooperating more closely with the colleges and universities, more emphasis would be laid upon oil engines and more students would be interested in the subject.

### The Outlook

From this survey it appears that the outlook for the future is nothing but promising. The oil-engine industry, which survived in spite of the numerous handicaps, may look for something better if the handicaps are removed. Technical progress is satisfactory, and with intelligent effort it will be accelerated. A tremendous market is here, of which only a small fraction has been exploited so far. There is room for every one. We have little doubt that we shall see a spectacular expansion of the oil-engine industry in the near future. We wish that a happy and prosperous New Year may mark the beginning of it.

The undersigned wishes to acknowledge his indebtedness to all those companies and individuals that have submitted information and thus assisted in preparing this Report.

P. H. Schweitzer.

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# Experimental Combustion Chambers Designed for High-Speed Diesel Engines

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*In this paper the preliminary requirement of the high-speed fuel-injection-engine problem is given, and analyses of the cycles used in this type of engine are included. There is also given a discussion of the effect of increasing speeds on the output of engines employing these cycles. The requirements of combustion chambers are set forth and results of experiments using three different types are given. The engine and testing apparatus are fully described and illustrated, and curves showing the performance of the engine when equipped with each of the special types of chambers are also shown.*

THE DESIGN of combustion chambers to meet the requirements of high-speed Diesel engines forms a part of the National Advisory Committee for Aeronautics' research program on the fundamental principles of fuel-injection engines. An outline of the proposed research on aircraft-type fuel-injection engines was prepared in 1920 at the request of the Bureau of Engineering of the Navy Department, which was interested in the development of these engines as power plants for large airships. Since that time progress has steadily been made toward the development of a high-capacity fuel-injection engine for aeronautical use.

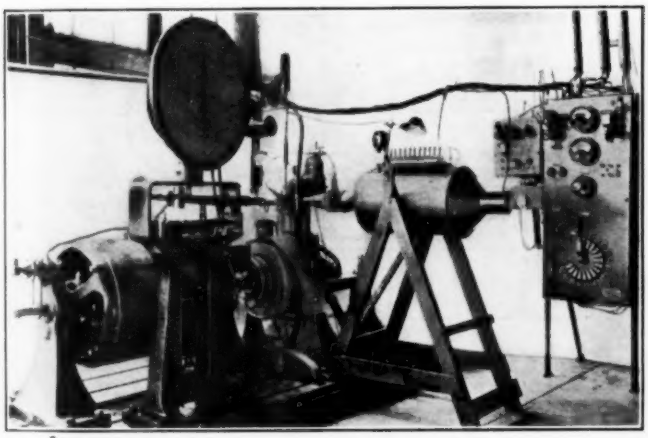

FIG. 1 ARRANGEMENT OF TEST ENGINE AND APPARATUS

In order to compete with present-day carburetor engines, it is necessary that the weight-power ratio of the fuel-injection engine be reduced from 25 lb. per hp. to a value of approximately 3 lb. This reduction in weight may be brought about by increasing the speed of the fuel-injection engine from the relatively low speeds of 300 to 600 r.p.m. to a speed of 1800 r.p.m. The attainment of this engine speed in a fuel-injection engine is complicated, however, by the problems of spray distribution and atomization, turbulence, and the time required for vaporization and ignition of the fuel. Consider a four-stroke-cycle engine running at 1800 r.p.m. and having an injection interval of 30 deg. The time corresponding to this interval of injection is approximately 0.003 sec. The time lag of ignition, as determined for slow- and medium-speed fuel-injection engines, depends upon the combustion-chamber design and the type of fuel-injection system, an average value, however, being approximately 0.020 sec. If the capacity of the fuel-injection engine is to be increased at high engine speeds, then it is necessary that the time lag for ignition be shortened or the entire charge of fuel will be injected into the cylinder and combustion will take place at constant volume with resulting excessive explosion pressures.

A preliminary requirement of the high-speed fuel-injection-engine problem is the selection of a possible engine cycle to give high efficiencies without requiring excessive cylinder pressures. An analysis of the Otto or constant-volume cycle shows that its use with compression pressures sufficiently high to cause auto-ignition of the fuel presents difficulties, due to the resulting high explosion pressures. An analysis of the Diesel or constant-pressure cycle shows that the cut-off ratio, which is defined as the ratio of the volume of the cylinder contents at cut-off to the clearance volume, to give the required mean effective pressure would result in values greater than 2.00. At high engine speeds this value of cut-off ratio would probably result in after-burning, with excessive fuel consumptions. The limitations of the above cycles have led to the adoption of the dual combustion cycle, in which a small portion of the fuel charge burns at constant volume and the remainder at constant pressure.[2]

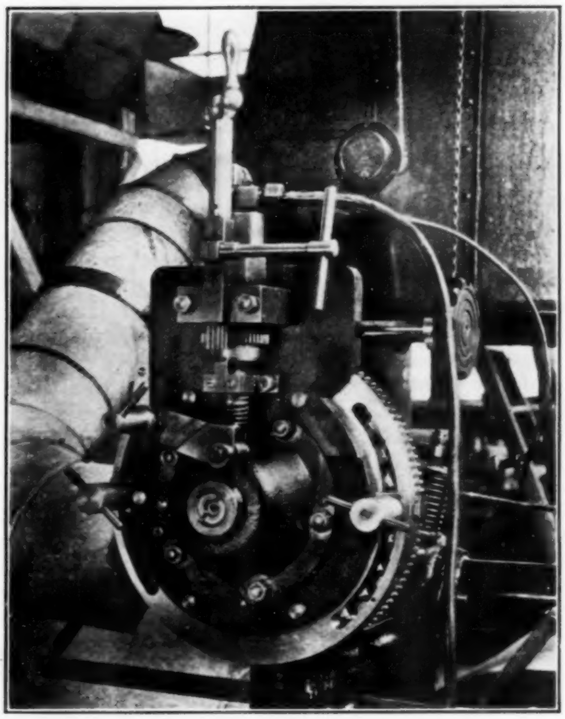

FIG. 2 CAM-ACTUATED FUEL-INJECTION PUMP

[1] Junior Mechanical Engineer, National Advisory Committee for Aeronautics.

Contributed by the Oil and Gas Power Division and presented at the Spring Meeting, White Sulphur Springs, W. Va., May 23 to 26, 1927, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

[2] "Thermodynamic Cycles in Relation to the Design and Future Development of Internal Combustion Engines," William J. Walker, Ph.D. Proceedings of the Institution of Mechanical Engineers, vol. 2, p. 1235, 1920.

This cycle is approximated in several large, low-speed oil engines. In operation these engines burn a small part of the fuel charge at constant volume, which raises the pressure and temperature enough to burn the remainder of the fuel charge at constant pressure.

Before high-speed fuel-injection engines can be built to run on the dual combustion cycle it is necessary that the fuel system

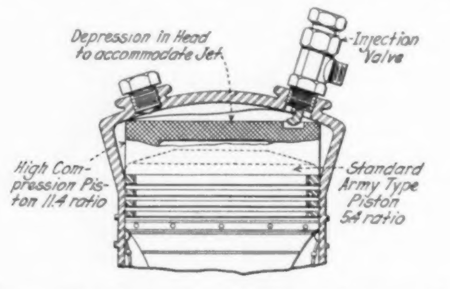


Fig. 3 Combustion Chamber of Standard Liberty Cylinder As Used for Fuel-Injection Research

so prepare the fuel that it will ignite almost instantly on injection. If the fuel charge injected by the valve has no time lag of ignition, then the principal requirement of the combustion chamber is to produce enough turbulence to cause complete combustion of the fuel. This is somewhat of an ideal condition, since the fuel injected at present is not a vapor but an atomized liquid.

Because of the time lag of ignition of the fuel with present

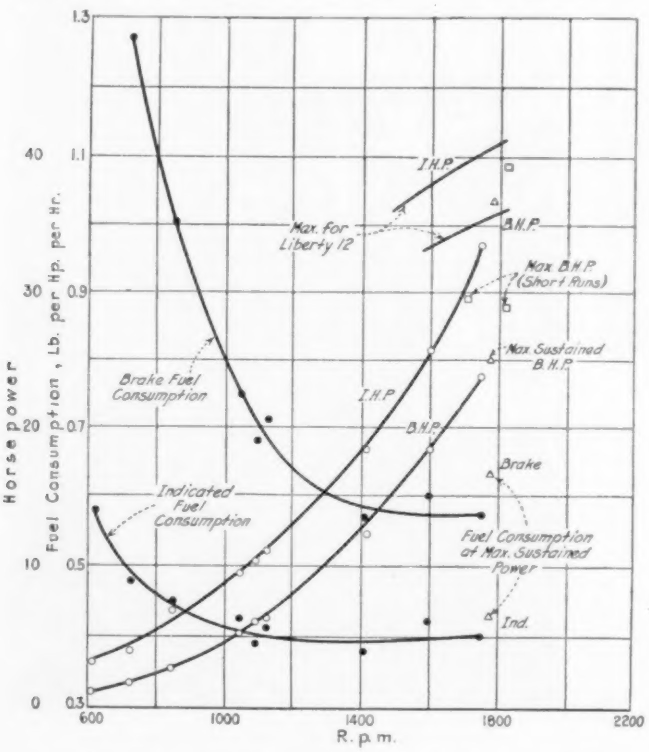


Fig. 4 Single-Cylinder Liberty Engine, Compression Ignition, Fuel Consumption at Part Loads

(Propeller load, 24 b.hp. at 1750 r.p.m. taken as normal. Lip-nozzle diam., 0.18 in.; compression ratio, 11.4:1; Diesel-engine oil.)

fuel-injection systems, the injection of the complete fuel charge into a high-speed engine results in substantially constant-volume combustion of a large part of the fuel charge, resulting in explosion pressures which may exceed 1600 lb. gage. In order to avoid these excessive explosion pressures many engine designers use a precombustion chamber in which the fuel is partially burned, further combustion of the fuel taking place in the cylinder proper. The connecting neck or orifice between the two chambers is proportioned to meter the products of the partial combustion in the precombustion chamber to obtain constant-pressure combustion in the cylinder.

This method of metering the burning gases to give combustion at constant pressure is not thought to be the solution of the fuel-injection problem for high-speed fuel-injection engines. Although the precombustion chamber makes possible the burning of heavy fuel oils without admixture of a volatile element, the use of the orifice at high engine speeds increases the thermal and reduces the mechanical efficiency of the engine. It may be shown that the use of the orifice results in the following losses: First, a friction or pumping loss of the gas due to forcing it through the orifice at high velocity; second, a loss in piston pressure caused by the lag of the gas pressure; and third, an increase in the heat loss to the jacket water, due to the scrubbing action of the gases. The use of the orifice, however, makes possible the attainment of a high degree of turbulence and improved

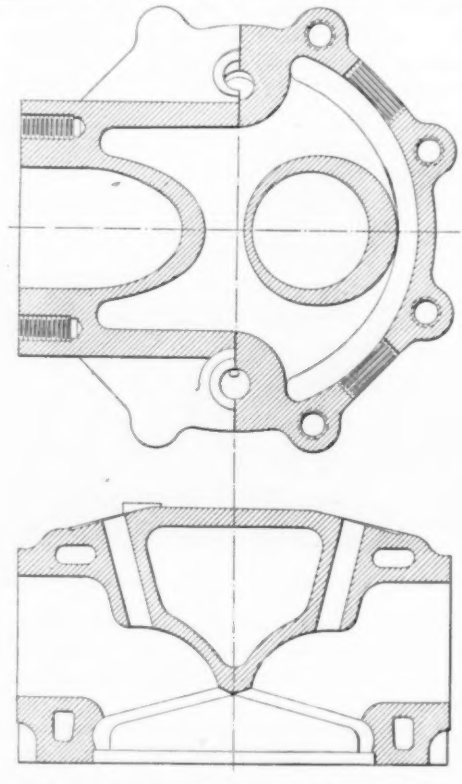

Fig. 5 Combustion-Chamber Design No. 1

combustion efficiency. This improvement in efficiency is shown by the lower fuel consumption when taken on an indicated-horsepower basis.

## Requirements of Combustion Chambers

The type of combustion chamber having the lowest heat losses is that presenting the least surface area for a given volume. If this were the only requirement it would lead to the design of spherical combustion chambers. For actual engine operation, however, there are other requirements, such as provision for turbulence, location of valves, simplicity, and ease of construction, which prohibit the use of the spherical combustion chamber.

In the design of combustion chambers for high-speed fuel-injection engines the most important requirements are, first, that the fuel spray shall be completely distributed throughout the combustion chamber, and second, that the degree of turbulence shall be sufficient to produce complete burning of the fuel in the short time available. It is only recently that reliable data have been obtained as to the behavior of fuel sprays when injected into gases under pressure. The data obtained by the National Advisory Committee for Aeronautics in its investigation of oil sprays for fuel-injection engines, by means of ultra-high-speed photographic apparatus, enable the combustion chamber to be designed to fit the fuel spray. The other requirements for fuel-injection-engine combustion chambers are the same for any type of combustion chamber. Thus the combustion chamber must be designed mechanically strong enough to withstand the explosion pressures. It must also give a rapid dissipation of heat and prevent large differences in temperature which may lead to cracking of the cylinder head. Particular attention should be given to the location of the inlet valve to provide an unobstructed flow of the air into the cylinder.

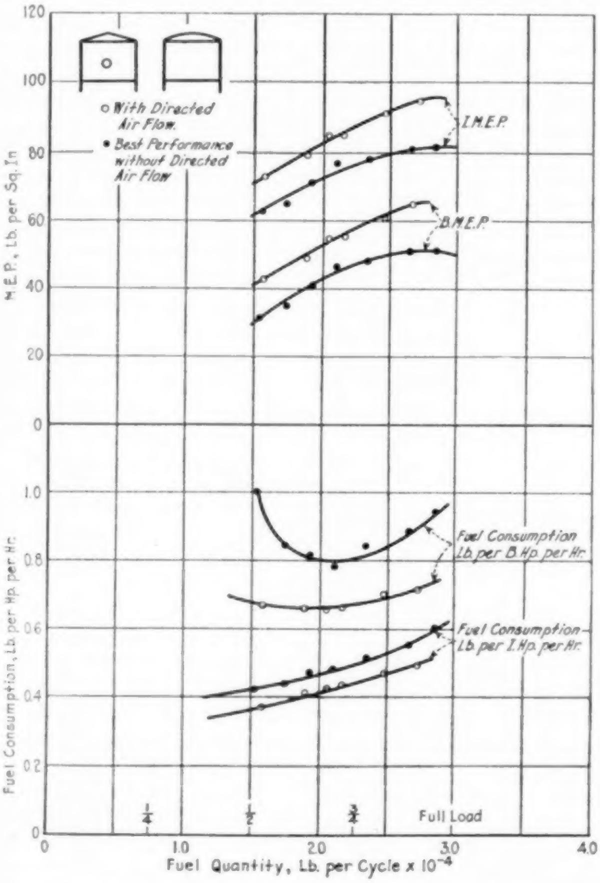


FIG. 6 FUEL-INJECTION PERFORMANCE, LIBERTY TEST ENGINE, COMBUSTION CHAMBER NO. 1, HAVING DIRECTED FLOW OF INLET AIR

(Maximum explosion pressure, 800 lb. gage; speed, 1500 r.p.m.)

Some of the successful commercial fuel-injection engines have obtained the necessary turbulence by reducing the cross-section of the combustion chamber for a short distance and then enlarging it into a bulb-shaped chamber containing the inlet and exhaust valves and the fuel-injection valve. The flow of gas through the connecting orifice produces a high degree of turbulence, and if the entire charge of air is placed within the bulb when the piston is on top center, the degree of combustion obtained is usually good.

### Description of Engine and Apparatus

The engine tests which determine the performance of a given design of combustion chamber are made at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics on single-cylinder test engines having a 5-in. bore and a 7-in. stroke. The engines are coupled to 50–75-hp. electric cradle-type dynamometers. The cylinder heads are bolted to special steel cylinders which in turn are fastened to the engine crankcase. The test engines use standard airplane-engine valves, pistons, and connecting rods. Arrangements are provided to maintain fuel-oil and water temperatures at constant values. A general view of one of the engines and test apparatus is shown in Fig. 1.

The fuel-injection system of this engine comprises, at present, a primary gear pump supplying oil at 90 lb. per sq. in. gage pressure to a cam-actuated impact type of injection pump, Fig. 2, and an automatic fuel-injection valve. The opening pressure and design of the fuel-injection valve control the pressure within the injection pump. The type of valve determines the necessary opening pressure, and for the present work, using a spring-loaded injection valve, the static opening pressure is 6000 lb. per sq. in. gage. The valve is so designed that the maximum injection pressure is also approximately 6000 lb. gage. The fuel used is a grade of Diesel fuel oil having a specific gravity of 0.847 at 80 deg. fahr.

The engine power is determined by means of a torque scale and a magnetically operated stop watch and counter. The fuel consumption is obtained by timing, with a stop watch, the flow of 200 cc. of fuel. The quantity of fuel delivered by the pump for any given pump adjustment may be determined from the total number of engine cycles passed through during the time the 200 cc. of fuel is burned.

The maximum cylinder pressures have formerly been determined by the use of a balanced-valve type of pressure gage. This has been replaced, however, by a diaphragm type of valve which is operated by the pressure of the gases within the cylinder. The pressure of the cylinder gases trapped above the diaphragm is indicated by a calibrated pressure gage. Engine tests have shown that it is unnecessary to provide means for cooling the diaphragm of this type of cylinder-pressure indicator. To obtain satisfactory results, however, the diaphragm of this gage must be protected from the formation of excessive carbon deposits.

### Combustion Chambers

For the preliminary testing of the operation of airless-injection engines at high speeds a standard Liberty aircraft-engine cylinder was used and fitted with a special aluminum piston to give a compression ratio of 11.4 to 1. The fuel pump used with this cylinder was designed to give a constant rate of injection independent of the engine speed. The combustion chamber is outlined in Fig. 3, and it may be noted that it was difficult to arrange a suitable fuel-injection valve to reach all the air in the combustion chamber. When operating under power it was found necessary to inject the fuel charge into the cylinder 50 deg. before top center in order to obtain reasonably good combustion. This long interval between injection and burning of the fuel charge resulted in explosion pressures of 1300 to 1600 lb. gage. The life of the aluminum pistons when operating under the above conditions was found to be very short. The force of the explosion either cracked the piston crown or the piston-pin bosses. Sufficient data were obtained, however, to indicate the possibilities of running fuel-injection engines at high speeds.

The curve of Fig. 4 indicates the power output and fuel economies obtained with the standard Liberty cylinder and a special piston giving a compression ratio of 11.4:1. It may be noted that the power output is 34 per cent less than that obtained per cylinder by the Liberty engine at a speed of 1750, and the fuel economy, 0.53 lb. per b.hp-hr., is 0.03 lb. per b.hp-hr. more than that obtained in the Liberty.

### Cylinder Head No. 1

The first combustion chamber designed for fuel-injection work is shown in Fig. 5. This design was recommended for test because of its uniform shape and simplicity of design. Due to the Liberty type of valve mechanism used on the test engine, it was

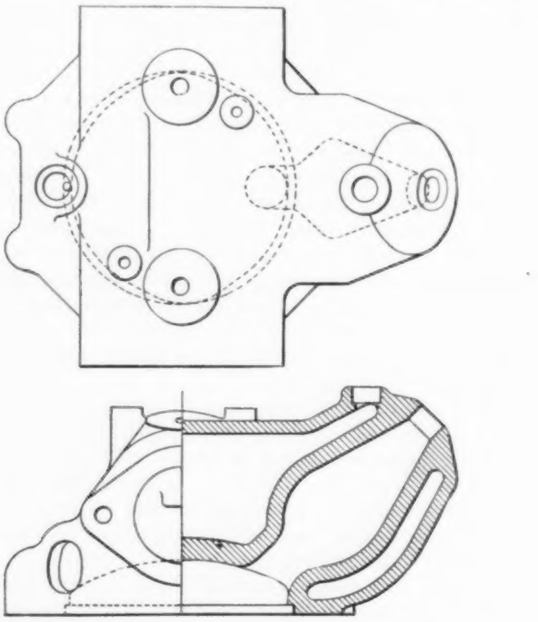

Fig. 7 Combustion-Chamber Design No. 2

impossible to place the fuel valve centrally in the combustion chamber. The only suitable fuel valve that could be used with this combustion chamber was one having an impact surface which produced a flat, fan-shaped spray of fuel. This cylinder head was tested with a standard Liberty Navy piston giving a compression ratio of 12.7 to 1.

This type of combustion chamber when fitted with a spring-loaded fuel-injection valve and an impact type of cam-operated fuel-injection pump gave poor performance. It was found possible, however, to vary the injection timing and to maintain maximum explosion pressures of 800 lb. gage. The performance with this type of combustion chamber was an improvement over that of the standard Liberty cylinder, in that the operation of the engine was smoother and no trouble was experienced with cracking of the standard aircraft aluminum pistons.

The experiment was tried of improving combustion by directing the flow of the inlet air through the inlet valve. The curves in Fig. 6 give the performance of this combustion chamber with and without directed air flow. It may be noted that it was found possible by directing the flow of the inlet air to increase the indicated mean effective pressure (i.m.e.p.) from 82.0 to 96.0 lb. gage with a corresponding decrease in the fuel consumption from 0.60 to 0.51 lb. per i.hp-hr. This increase in performance, obtained by directing the flow of the inlet air toward the fuel-injection valve, was thought to be caused by the complete removal of the products of combustion surrounding the fuel valve. The fuel, therefore, was injected into a charge of relatively pure air which gave improved combustion.

### Cylinder Head No. 2

Fig. 7 shows the outline of the first type of combustion chamber used having a bulb type of precombustion chamber. This cylinder head was fitted with a standard Army type of Liberty piston arranged to give a compression ratio of 9.9 to 1. The corresponding low-compression pressure of 280 lb. gage made for difficulty in starting from cold, and it was necessary to heat the jacket water or to preheat the inlet air.

As shown by the performance curve in Fig. 8, the combustion chamber, when fitted with an eccentric-driven fuel-injection pump and a diaphragm-type fuel-injection valve, gave better performance than either of the other two tested. The brake mean effective pressure (b.m.e.p.) at full load, which is considered as the fuel weight giving 15 per cent excess air, and 1800 r.p.m.

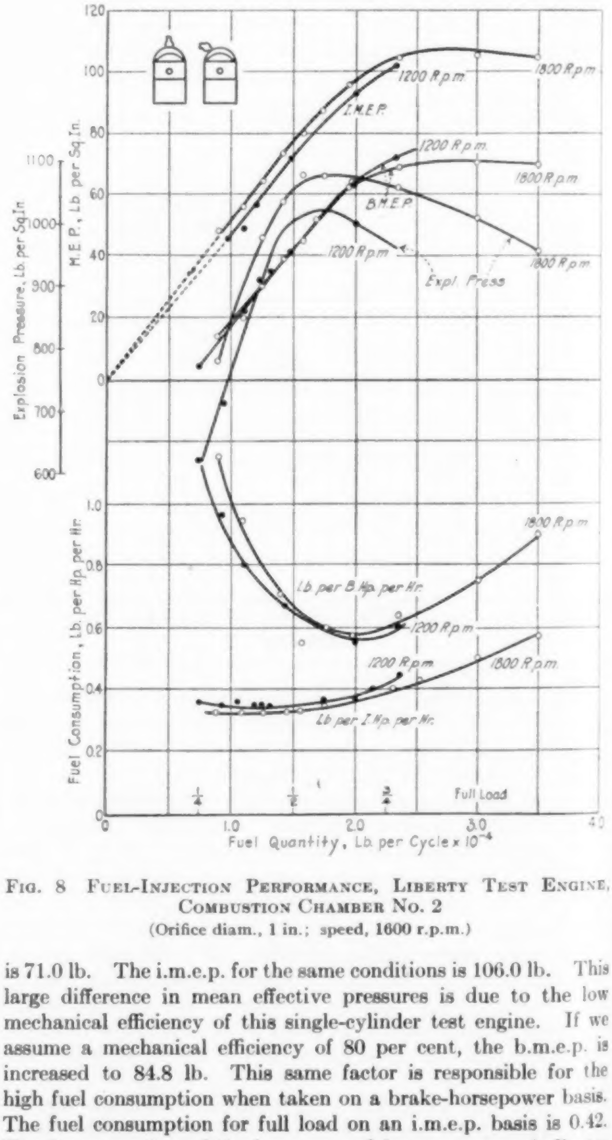


Fig. 8 Fuel-Injection Performance, Liberty Test Engine, Combustion Chamber No. 2
(Orifice diam., 1 in.; speed, 1600 r.p.m.)

is 71.0 lb. The i.m.e.p. for the same conditions is 106.0 lb. This large difference in mean effective pressures is due to the low mechanical efficiency of this single-cylinder test engine. If we assume a mechanical efficiency of 80 per cent, the b.m.e.p. is increased to 84.8 lb. This same factor is responsible for the high fuel consumption when taken on a brake-horsepower basis. The fuel consumption for full load on an i.m.e.p. basis is 0.42. The linear portion of the b.m.e.p. and i.m.e.p. curves indicates that for a fuel quantity of less than 0.0002 lb. per cycle, combustion is practically complete. For fuel quantities greater than this, however, the curves tend to flatten, which indicates that

the air within the cylinder is not supporting efficient combustion of the injected fuel. The curve of maximum pressures shown was plotted from data obtained with a balanced-valve type of maximum-explosion-pressure indicator. The ball of the indicator was balanced with nitrogen gas.

### Cylinder Head No. 3

A third type of combustion chamber was designed to give a high degree of turbulence within the pear-shaped bulb on the compression stroke and within the cylinder on the expansion stroke. This high degree of turbulence was obtained by locating the $^9/_{16}$-in. orifice to direct the air flow tangentially into the bulb and also produce a tangential discharge of the products of the partial combustion within the bulb into the cylinder. The ratio of the volume of air in the bulb to the volume of air in the cylinder was approximately 1 when the piston was on top center. This head was tested with a compression ratio of 13.5 to 1, the compression pressure obtained in the engine being 450 lb. gage. The operation of this combustion chamber under all loads was smooth and regular. For full-load operation at 1800 r.p.m. the b.m.e.p. with a mechanical efficiency of 80 per cent was approximately 85.0 lb. The corresponding fuel consumption was 0.60 lb. per b.hp-hr.

Tests have shown that the power output may be increased approximately 8 per cent by rounding the orifice edges and flaring it to discharge the burning gases over one-half the piston area. Results indicate that flaring the orifice has permitted the fuel from the bulb to reach more of the air in the cylinder.

### Conclusions

In conclusion it may be said that the performance of combustion chambers designed to give partial combustion and a controlled amount of turbulence, indicates that it is possible to increase the r.p.m. of the fuel-injection engine without encountering excessive explosion pressures. The tests completed emphasize the fact that an increase in capacity of the high-speed fuel-injection engine depends upon the ability to obtain higher mean effective pressures and an improvement in the mechanical efficiency of the engine.

Increasing the mean effective pressure above its present relatively low value, as compared with the carburetor engine, depends primarily upon complete mixing of well-atomized fuel with the air charge and the reduction of the time lag of ignition. The required amount of turbulence to give complete mixing of the fuel and air may be obtained by the design of the combustion chamber. It is believed, however, that the necesssry reduction in the time lag of ignition can only be brought about by better preparation of the fuel charge before injection into the engine.

The problem of increasing the mechanical efficiency of the engine and reducing its weight may be solved by an application of the engine design and construction principles of the aeronautic engine.

## Discussion

Robertson Mathews.[3] The limitations of our engineering diction are so often encountered that the writer feels inclined to take exception to the title of Mr. Kemper's paper. He would like to see "airless-injection" substituted for "Diesel." It is particularly important that papers of this character bearing on engine development contain no false terminology. Future research workers may come to doubt the value of records in which engines that use no air for injection and operate either on the Otto or else the dual combustion cycle, have been called Diesels. The fame of Dr. Diesel requires no false diction.

[3] Detroit, Mich.

One note that is struck in this paper is particularly pleasing, namely, the considerable emphasis of the weak points of the problem. Still more stress could probably have been placed upon the disadvantages of the bulb design. Since the size of engine under consideration is likely to be called upon to serve a field requiring wide flexibility, the self-timing of the fuel distribution by the bulb is not attractive.

The loss of effective effort upon the piston owing to the restricted flow of gases through the neck of the bulb, is an item that has appealed to the writer's curiosity for a long time. On the one hand there is a piston that is moving relatively slowly compared with the nozzle velocity of gases. On the other hand there is the differential pressure through the neck required to produce a gas velocity sufficient for the gas to follow the piston. A discussion with numerical determinations for this problem might be of interest.

Since the data show that the engine was operated at as widely different speeds as 1200 and 1800 r.p.m., it is regretted that the paper could not have been of sufficient length to qualify further some important statements. Under "Description of Engine and Apparatus" the author states that the valve is so designed that the maximum injection pressure is also approximately 6000 lb. gage. Either a highly interesting nozzle has been designed or the stated pressure applies to some particular r.p.m. In the second paragraph of the paper we read: "The time lag of ignition, as determined for slow- and medium-speed fuel-injection engines, depends upon the combustion-chamber design and the type of fuel-injection system, an average value, etc." This statement seems worthy of more attention in view of a later statement. Among the conclusions, we read: "It is believed, however, that the necessary reduction in the time lag of ignition can only be brought about by better preparation of the fuel charge before injection into the engine." This is a strong statement. It appears like a veiled recognition of the limitation of the time required for vaporization. Having arrived thus far the writer would like to see the N.A.C.A. attack with vigor the problem of the determination of the time limits to the rate of fuel vaporization.

Alan E. L. Chorlton.[4] With regard to smaller engines running at high speed, the opportunities of varying the form of the combustion chamber are really very small, and the Akroyd-Stuart type with reduced connecting duct between the chamber and the cylinder proper is hardly admissible, because the air outside the combustion chamber, as it cannot be all attacked or fuelized by the injection fuel, brings of necessity results with this type of chamber which have lower mean pressures than the plain type, that is, as in design No. 1.

When the writer began development work in connection with high-speed engines some six years ago, both types were considered, and as in his country (England) information was available regarding the Akroyd-Stuart type, it could, from his own practical experience, be rapidly compared with the other before a beginning was made. However, engines of both types were constructed.

The result of years of work on this form of engine is that the No. 1 type is the preferred one for the smaller, quick-running type, with plain injection and without an explosion cup or antechamber; it is thought that this will be the ultimate form. A number of engines of this type have now been built, and the accompanying tabulated results of some tests were given by the writer in a paper before the Institution of Mechanical Engineers.

While further experiments have since been made, these results

[4] Chief Engineer, Wm. Beardmore & Co., Ltd., London, England. Mem. A.S.M.E.

| Test series | Duration of test, hours | Speeds, r.p.m. | B.hp. | Fuel, lb. per b.hp-hr. | Cooling-water temperatures: Inlet, deg. fahr. | Cooling-water temperatures: Outlet, deg. fahr. | Fuel |
|---|---|---|---|---|---|---|---|
| A | $4^1/_4$ | 689.3 | 160.26 | 0.418 | 121.5 | 127.4 | Shell Mex Diesel |
| B | 3 | 700.0 | 172.0 | 0.385 | 120.0 | 128.0 | Shell Mex Diesel |
| C | 3 | 1007.0 | 424.0 | 0.365 | 140.0 | 150.0 | Shell Mex Diesel |
| D | 1 | 1023.3 | 263.0 | 0.355 | 181.0 | 185.5 | Anglo-Persian |

indicate how this engine has quite passed out of the experimental stage, and in fact numbers of them are now under construction for widely different purposes such as airships, railways, locomotives, and other power productions, etc.

It will interest members to know that as development work has gone on, mean pressures have gradually been raised, until now we have on test indicated mean pressures of as high as 150 lb. without supercharge, running at 1000 r.p.m., with a fuel consumption of less than 0.35 lb. per b.hp-hr.

The mechanical efficiency of such engines is usually 85 per cent, which of course means a correspondingly good economy as compared with the indicated power, and further, less wear and tear.

It does appear from practical experience with these engines, owing to the high class of manufacture and the thin-walled, less-heat-stressed material that can be put into them, that despite their speed they appear to have longer lives in front of them than the thick-walled, slow-speed marine engines.

Regarding the author's remarks concerning fuel injection at the end of the second paragraph of the paper, the writer would suggest to him that to get the best results he should aim for, instead of being opposed to, more combustion at constant volume, and design his engine to operate with such high pressures. He will find, it is believed, that the general move will ultimately be in this direction.

The dual cycle is really a method of analyzing a heat cycle theoretically, rather than a new cycle. The conditions in any of the cycles in actual practice do not conform to the theoretical, and therefore allowances have to be made for them in all cases as in specific heat, dissociation, and after-burning.

The practical variation when working in principle at constant-volume combustion would be by graduating the discharge of the fuel—that is to say, reducing it in the earlier part; thus the results of tests indicated previously are obtained with the maximum pressure not exceeding 800 lb. and in effect, therefore, some constant-pressure working is achieved. In any case, however, delayed combustion or after-burning must be avoided with quick-running engines.

The writer notes what is said in regard to the precombustion chamber, and on the whole agrees with the author. The general trend in development is always to simplify, and the precombustion chamber will go in time.

With reference to the question of turbulence, one often wonders whether this important factor is not being rather overstressed. At any rate, in the high-speed engine the rate of burning on the constant-volume cycle produces pressures for which undue turbulence does not seem necessary. Thus the extra turbulence set up in the Akroyd-Stuart engine, due to the neck, which has been found to be useful for the slower-speed engines, does not seem necessary for the high-speed. No doubt the whole matter is composed of variables such as the speed of injection, the turbulence, the form of atomization, so combined that it is difficult to allocate correct and separate values to each. Where the atomization of fuelizing of the air is not so good, then, relatively, turbulence must be increased.

In the writer's practical experience, he has not so far passed 1400 r.p.m., but as this was for a relatively large cylinder—as small cylinders go—viz., $8^1/_4$ in. × 12 in., the speed of combustion indicated that higher speeds should be capable of attainment. Actually the least loading of parts, due to the action of inertia, took place at 1350 r.p.m.

With reference to the weight of the engine, in the writer's experience the engine weight when the crankcase is built of aluminum alloy can be obtained at even less than the 3 lb. per b.hp. indicated in the paper.

A great deal of work has been done in connection with sprays, and a comparison of all this work is urgently needed.

From the writer's experience with high-speed engines, it does seem that the pump used, together with its fluid circuit, hydraulic-ram effect, etc., and the spraying mechanism, is the most important feature of the whole problem. More so, perhaps, than the forms of the combustion chamber (which because of the engine sizes are really very limited) and the question of turbulence, which latter the writer is prone to think is somewhat overstressed at the present time.

The form of apparatus to be used for measuring the fuel for multi-cylinder engines requires to be of a singularly accurate and consistent type. Experimental tests with one cylinder may show quite good results, but with an 8-cylinder engine, unless all cylinders are adjusted within a very narrow margin the results will be considerably inferior.

The production of a special piece of apparatus for this work is therefore highly important. The question of the form of atomizer itself is also of great importance.

The work done by the writer's company in this direction indicates that an airplane engine can be constructed with weights very little in excess of those now common. Taking, for instance, the air-cooled radial as the type, it indicates that figures of consumption of 0.35 lb. per b.hp-hr. can be obtained, and with the advent of the exhaust-driven turbine it does not seem unreasonable to look forward to as low a figure as 0.3 lb. per b.hp-hr. within the next two years with the further development work now going on with the engine proper.

As a member in another country, but by periodic visits alive to the urge present in all American investigations, the writer would like to suggest to the Society that it take upon itself the duty of correlating the experimental work now going on so that all of it shall be pursued on agreed lines and no overlapping shall occur.

In the oral discussion following the reading of the written communications, L. H. Morrison[5] asked whether in obtaining turbulence the author made use of a director or deflector such as the Hesselman, whether with different speeds better results were obtained by changing such a deflector and how the 15 per cent excess-air figure was arrived at.

Wm. T. Magruder[6] asked if the low volatility and slow-burning properties of Diesel-engine oils did not limit the speed of the engine. At 1000 r.p.m. or even 2000 r.p.m. it might be possible to burn the fuel, but when it came to 4000 r.p.m. it would not even have time to ignite.

The Author. In regard to the discussion by Mr. Chorlton what he says may be true. That is, we may be giving too much attention to turbulence, but at the present time, from what we have done, it would seem to be absolutely necessary for high-speed work. We may be wrong about the type of fuel combustion chamber that we are using at present, but from the results we have obtained it shows an improvement over the other types we have tried. We have to admit that the plain type to which

[5] Associate Editor, *Power*, New York, N. Y., Assoc-Mem. A.S.M.E. and Chairman of session at which Mr. Kemper's paper was presented.

[6] Professor of Mechanical Engineering, Ohio State University, Columbus, Ohio. Vice-President A.S.M.E.

Mr. Chorlton refers was not given a fair trial due to the fact that we were not able to locate a fuel valve centrally in the combustion chamber.

Referring to Chairman Morrison's questions, the Hesselman has a deflector mounted on the inlet valve. Our deflector was inserted in the inlet manifold so as to direct the air around the inlet valve. We hit upon the idea about the first time we started our fuel-injection work, but it was not tried until later. Soon after we made our experiments Hesselman brought out his engine in which the same principle is used.

No better results were obtained by changing the deflector. The work done, it should be understood, was not intended to be a report. It is merely a short technical note of something that we stumbled on accidentally. It is interesting to see that some time after we stumbled on it, or at about the same time, Hesselman brought out an engine in which diverted turbulence was the basic principle. But that work has been discontinued. Our big problem now, is to get the b.m.e.p. somewhere around 130 lb. per sq. in.

We are at the same time carrying on a theoretical analysis of the variation of specific heats with variation of temperature, and from the data calculated so far we have been able to compute a probable value. Of course, we are not exact, but the value is somewhere close. The committee at present is doing a good deal of work on the variation of the specific heats of the gases of combustion. When it is completed, we should then be able to say whether it is 14.9 or 16.6 per cent excess air or some such definite figure. It is somewhere in the neighborhood of 15 per cent. We have done the best we could to arrive at a volumetric efficiency and also determine the compression ratio of the pistons, etc. With the data we have been able to obtain at present, we have made corrections for everything that we could.

In reply to Professor Magruder, it may be said that we might so prepare the fuel that when it goes into the engine cylinder it is all ready to burn. That is a problem that we are now taking up. If we can heat up the fuel and keep it under pressure so that the instant the valve opens we inject a vapor, then the time lag of ignition is gone.

# The Study of Oil Sprays for Fuel-Injection Engines by Means of High-Speed Motion Pictures

By EDWARD G. BEARDSLEY,[1] LANGLEY FIELD, HAMPTON, VA.

*Apparatus for recording photographically the start, growth, and cut-off of oil sprays from injection valves has been developed at the Laboratory of the National Advisory Committee for Aeronautics at Langley Field, Va. The apparatus consists of a high-tension transformer by means of which a bank of condensers is charged to a high voltage. The controlled discharge of these condensers in sequence, at a rate of several thousand per second, produces electric sparks of sufficient intensity to illuminate the moving spray for photographing it. The sprays are injected from various types of valves into a chamber containing gases at pressures up to 600 lb. per sq. in.*

*Several series of pictures are shown. The results give the effects of injection pressure, chamber pressure, specific gravity of the fuel oil used, and injection-valve design, upon spray characteristics.*

THE FIRST successful compression-ignition oil engine, using air injection, was built about 1897 by Dr. Diesel. It was not until about 1912 that McKechnie constructed the first practicable so-called solid- or hydraulic-injection engine. Since that time the solid-injection engine has been gradually developed and the demand for it has so increased that today a considerable number of engine builders are manufacturing this type. Much progress has been made, and a great deal of knowledge has been gained concerning solid-injection engines.

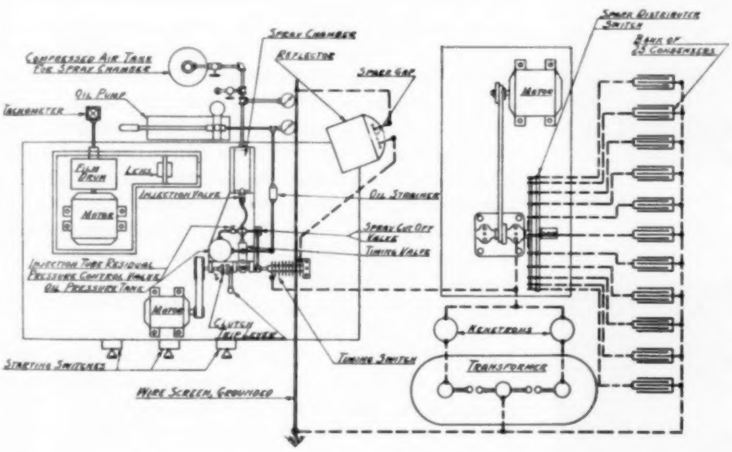


FIG. 1 DIAGRAMMATIC ARRANGEMENT OF SPRAY-PHOTOGRAPHY APPARATUS

The part of the engine about whose operation we have the least information thus far, is probably one of the most important parts, namely, the injection valve. Sprays from injection valves have been examined in the atmosphere as to their cone angle, fineness of atomization, and rapidity of combustion when ignited. They have been injected into water and the penetration noted visually. However, the complete behavior of a spray injected into dense air has always been a matter for conjecture and theoretical computation. Yet it is something which is very important, and because of this lack of definite knowledge the design of an injection valve to give the best results in a particular combustion chamber has been to a large degree a process of cut and try.

The study of the compression-ignition, solid-injection type of engine, with regard to its possible development for aircraft use, was started at the Langley Memorial Aeronautical Laboratory at Langley Field, Va., in 1921. The general problem was analyzed and an attempt made to attack it from all angles. One of the things about which actual knowledge was desired was the characteristics of sprays from injection valves. While the fit between the spray and the combustion chamber is not of so much importance in the case of a low-speed, low-capacity engine, it is vital for the high-speed, high-capacity engine useful for aircraft. The spray was therefore to be studied with regard to its penetration, general shape, and atomization when injected into dense air.

It was thought that the method by which it would be possible to obtain the greatest amount of information about oil sprays was to take high-speed motion pictures of their start, development, and cut-off, which would show their penetration, general shape, and possibly their atomization. With this end in view preliminary apparatus was designed, built, and tested during the summer of 1921. How-

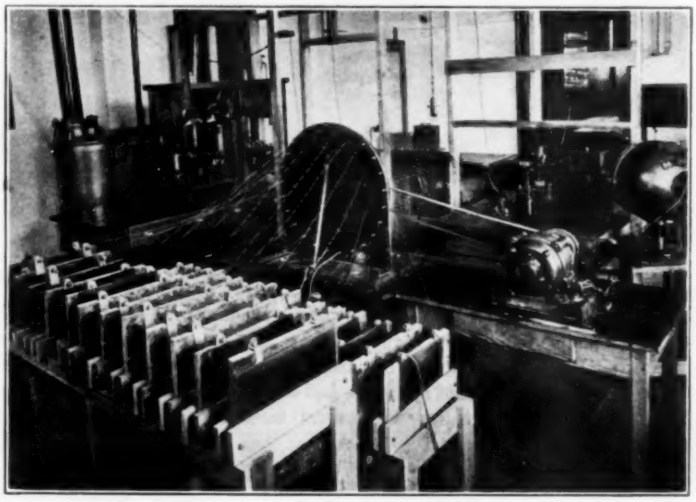

FIG. 2 GENERAL VIEW OF SPRAY-PHOTOGRAPHY APPARATUS

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Contributed by the Oil and Gas Power Division and presented at the Spring Meeting, White Sulphur Springs, W. Va., May 23 to 26, 1927, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

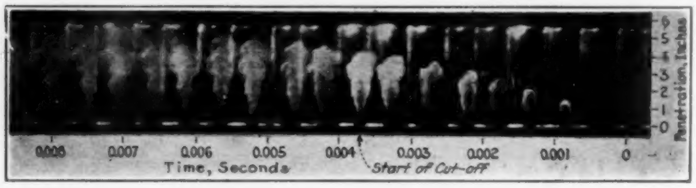


FIG. 3 MEDIUM-CENTRIFUGAL SPRAY FROM INJECTION VALVE NO. 7

(Diesel oil at 0.85 specific gravity injected at 8000 lb. per sq. in.; compressed air at 200 lb. per sq. in. in chamber.)

The following information is obtained from a series of pictures similar to the above:

*Visual Studies.* General spray form; peculiarities in spray form; cut-off; phenomena occurring after cut-off; atomization of spray.

*Measurements and Computations.* Spray penetration with time; time of cut-off after spray starts; spray-cone angle; volumetric growth of spray; spray distribution.

*Effects of Variables.* Effects of injection pressure; effect of chamber-gas density; effect of specific gravity of fuel oil; effect of injection-valve design; effect of injection system.

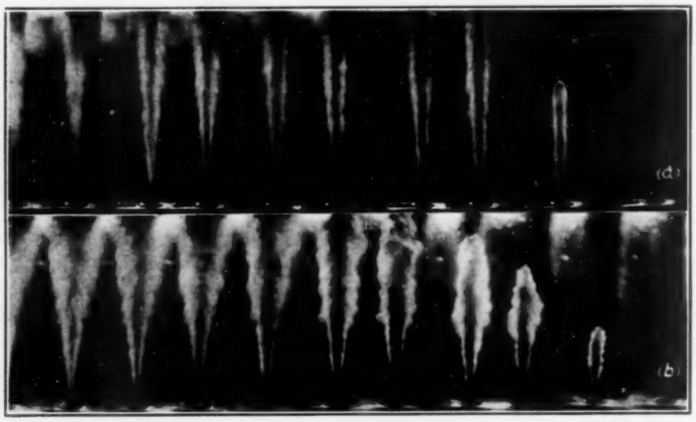


FIG. 4 EFFECT OF CHAMBER PRESSURE ON A NON-CENTRIFUGAL SPRAY

(a) Injection pressure, 8000 lb. per sq. in.; chamber pressure, atmospheric.
(b) Injection pressure, 8000 lb. per sq. in.; chamber pressure, 200 lb. per sq. in.

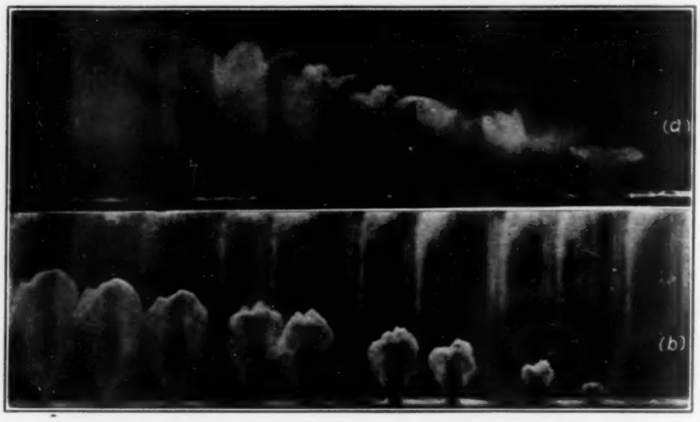


FIG. 5 EFFECT OF CHAMBER PRESSURE ON A HIGH-CENTRIFUGAL SPRAY

(a) Injection pressure, 8000 lb. per sq. in.; chamber pressure, atmospheric.
(b) Injection pressure, 8000 lb. per sq. in.; chamber pressure, 200 lb. per sq. in.

ever, it was found impossible to obtain a series of pictures of oil sprays with the apparatus then in use. Finally, in the fall of 1924, the photography of oil sprays in dense air became a reality. From that time to the present day much improvement has been made in the apparatus and methods, and considerable knowledge has been gained concerning the several factors governing the characteristics of oil sprays.

## RANGE OF INVESTIGATION

Various researches have been carried on with the present apparatus to determine the effects of injection pressure, chamber pressure and gas density, fuel oil used, and injection-valve design on oil sprays. Thus the development of single sprays with time, their velocities, penetration, distribution, form, spray-cone angles, actual volumes, and relative atomization are determined for various types and designs of injection valves. Several phenomena connected with injection hydraulics have also been investigated.

The injection valves studied include mechanically operated valves, and automatic-injection valves especially developed for high-speed operation. The sprays are discharged from round orifices with or without directing impact surfaces, and through annular orifices. Spiral grooves with helix angles of from 23 to 90 deg. have been used to break up the spray by means of centrifugal force. The former groove angle gives a spray to which about the maximum amount of centrifugal force practicable has been applied, while the latter gives a non-centrifugal spray.

## APPARATUS FOR TAKING ULTRA-HIGH-SPEED MOTION PICTURES

The problems involved in taking moving pictures of oil sprays from injection valves presented numerous difficulties. The two outstanding problems were the necessity of having a duration of exposure of about a millionth of a second, and the production of photographic records, with this short exposure, at a rate of several thousand a second. The extremely short duration of exposure necessary can be easily computed by assuming that the spray has an initial velocity of 500 ft. per sec., or 6000 in. per sec., and permitting a distortion of $^1/_{100}$ in. of the spray image recorded on a photographic film. For these conditions the duration of exposure must not be more than $^1/_{600,000}$ sec. Calculations will show that it would be practically impossible to build a mechanically operated shutter which would give such a brief exposure. Also, with this infinitesimal duration of exposure the illumination must be very intense in order to produce a satisfactory record on the film. The only solution of the problem seemed to be to use the discharge of electrical condensers, thus eliminating mechanical shutters, the duration of the spark from a condenser discharge being known to be of the short time required.

The next requirement was that the series of pictures of the spray be taken at a rate of several thousand per second. This necessitated the use of a number of condensers arranged so that they could be discharged at the required frequency.

The first electrical system investigated consisted of fifteen Leyden jars, which were charged by a static machine. Because of the dampness of the climate the machine failed to charge satisfactorily, and also the Leyden jar condensers were too small.

A 100,000-volt transformer and kenetron rectifying tubes were next installed. A bank of 30-in. × 30-in. glass-plate condensers was built, but was unsuccessful because of excessive surface leakage and frequent puncturing of the glass plates. Twenty-five condensers were then built with micanite plates for dielectrics, and these have proved successful.

The present spray-photography apparatus, so far as is known, was the first apparatus ever built capable of recording by a series of pictures the growth of oil sprays. A diagrammatic layout of the apparatus is shown in Fig. 1 and a general view

is shown in Fig. 2. The electrical apparatus consists of a high-tension transformer, two kenetron rectifying tubes, a bank of twenty-five condensers, a rotating distributer switch, a timing switch, and a spark gap in front of a reflector for focusing the light on the moving oil spray. Figs. 1 and 2 show the transformer and kenetron rectifying tubes by means of which the twenty-five condensers are charged to 30,000 volts through the rotating distributer switch. One terminal of each condenser is connected to a contact on the switch panel, and the other is grounded. Discharge across the spark gap cannot take place until the timing switch operated by the camshaft is rotated, when each condenser is discharged in sequence across the gap. The frequency of the discharges is controlled by the speed of rotation of the distributer switch. This switch is of the rotating, multiple-break type, by means of which it is possible to make and break a high-tension circuit without serious arcing.

### The Injection System

The apparatus for the production and control of sprays is shown diagrammatically in the left-hand half of Fig. 1. It consists of a high-pressure hydraulic hand pump a pressure tank, timing valve, cut-off valve, initial-pressure control valve, motor-driven camshaft, and spray chamber.

The hydraulic hand pump used is of the ordinary plunger type and is capable of delivering oil at pressures up to 12,000 lb. per sq. in. The pressure tank provides a sufficient volume of oil under pressure to insure a practically constant pressure on the oil during the whole injection period. The timing valve consists of a spring-loaded needle valve which is lifted from its seat by a cam-operated lever. The cut-off valve is a poppet valve actuated by another cam-operated lever. The duration of injection is controlled by adjusting the lever along the cam so as to obtain earlier or later operation of the cut-off valve with respect to the timing valve. The mechanism is so designed that the amount and rate of opening of the valve is practically constant for all cut-off positions of the lever. The initial-pressure control valve, when opened, allows oil to be pumped directly into the injection-valve tube, either for testing the opening pressure of the valve or to provide the correct initial pressure in the injection-valve tube before injection.

The shaft carrying one half of the jaw clutch is driven at 900 r.p.m. by a motor. The clutch is similar to the type used on punch presses, and is so arranged that when the trip lever is struck the two halves of the clutch engage and the hollow shaft carrying the cams is given one revolution. The timing switch is connected to the camshaft by means of a serrated coupling and can be turned so that it will make contact at the proper time to synchronize the beginning of the sparks with the beginning of the spray.

The spray chamber is of cast iron, two sides of which are formed by frames holding optical-glass windows one inch thick, supported on rubber. The window frames are bolted on and sealed with rubber gaskets. Gas pressures up to 600 lb. per sq. in. are used in the chamber.

### The Recording Apparatus

The recording apparatus consists of a camera box containing a lens and a motor-driven film drum. To concentrate the light of the spark upon the spray a reflector is used. It will be noted from Fig. 1 that it is offset from the line of the

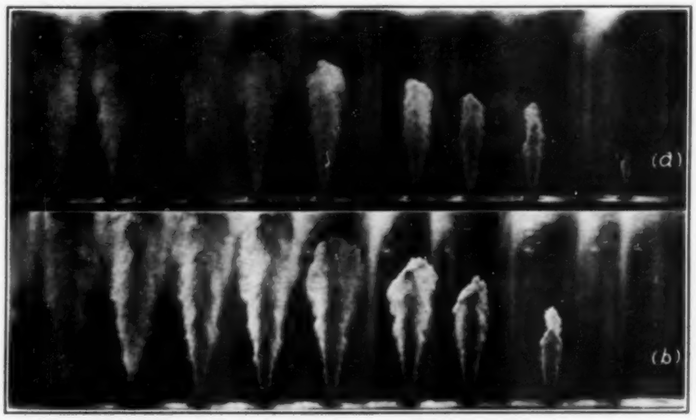

Fig. 6 Effect of Valve Size upon Centrifugal Sprays

(a) Ratio of orifice area to groove area, 0.19; orifice area, 0.000113 sq. in.; injection pressure, 8000 lb. per sq. in.; chamber pressure, 200 lb. per sq. in.
(b) Ratio of orifice area to groove area, 0.19; orifice area, 0.00038 sq. in.; injection pressure, 8000 lb. per sq. in.; chamber pressure, 200 lb. per sq. in.

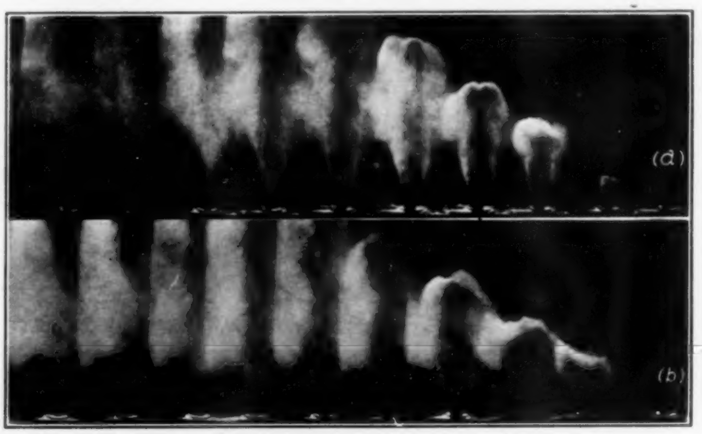

Fig. 7 Centrifugal Spray With and Without Secondary Discharge After Cut-Off

(a) Spray with secondary discharge. Injection pressure, 8000 lb. per sq. in., chamber pressure, atmospheric.
(b) Spray with no secondary discharge. Injection pressure, 8000 lb. per sq. in.; chamber pressure, atmospheric.

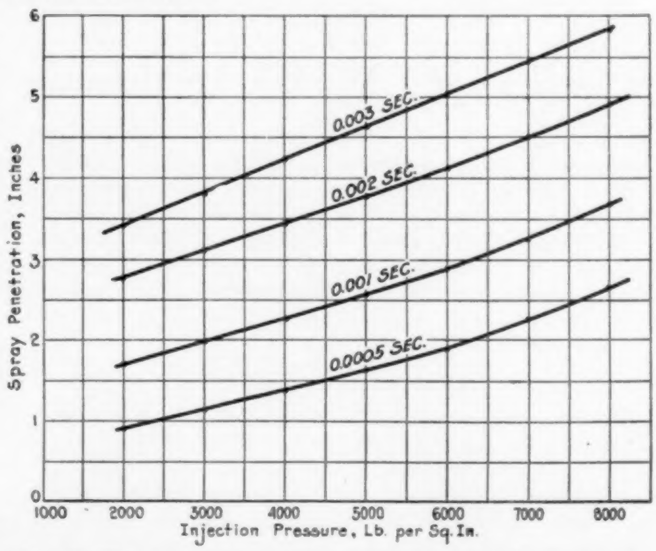


Fig. 8 Effect of Injection Pressure on Spray Penetration

(Injection valve No. 7; cylinder orifice, 0.0155 in. diam.; fuel used, Diesel oil of 0.85 specific gravity; nitrogen in spray chamber at 200 lb. per sq. in.)

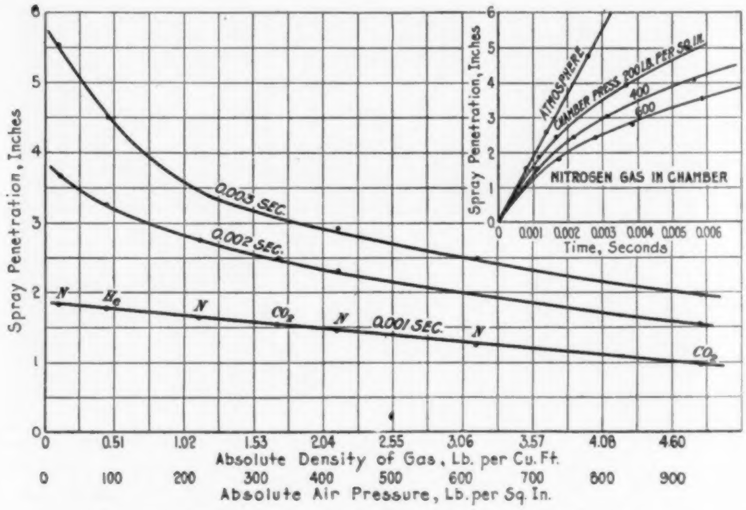


Fig. 9 Effect of Gas Density on Spray Penetration

(Injection valve No. 7; 23-deg. spiral grooves; 0.022 in. diam. of orifice; injection pressure, 8000 lb. per sq. in.; fuel used, Diesel oil of 0.85 specific gravity; gas in spray chamber, nitrogen, carbon dioxide, or helium.)

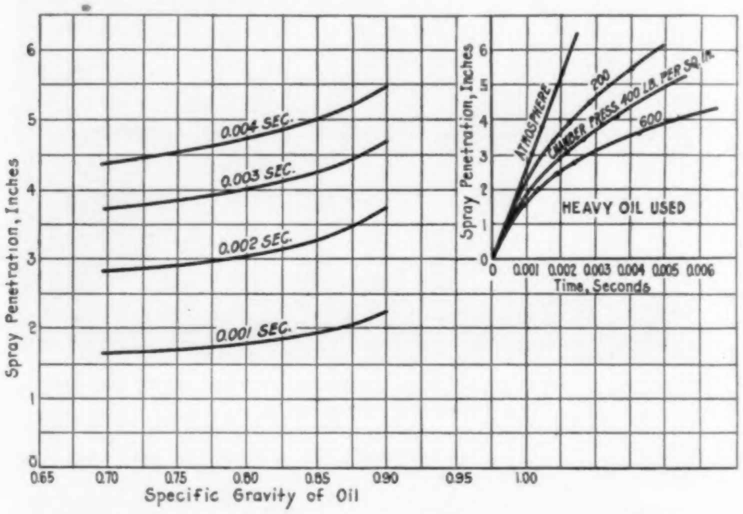


Fig. 10 Effect of Specific Gravity of Oil on Spray Penetration

(Injection valve No. 7; 23-deg. spiral grooves, 0.022 in. diam. orifice; injection pressure, 8000 lb. per sq. in.; fuel oil used, gasoline, kerosene, Diesel, and heavy fuel oil of specific gravity 0.705, 0.799, 0.85, and 0.90, respectively; air in spray chamber at 200 lb. per sq. in.)

chamber and film drum. Only the light refracted by the spray itself passes in through the lens and records the series of pictures of the moving spray upon the film. The film is fastened around a drum 30 in. in circumference which is mounted on the shaft of an electric motor. The speed of rotation of the film, together with the rate of discharge of the condensers, determines the spacing of pictures. An F:2 Taylor-Hobson Cooke lens is used. All pictures of the sprays are taken half-size on commercial photographic roll film.

## Operation of Apparatus

The operation of the apparatus is as follows: The initial pressure in the injection-valve tube is adjusted, after which the control valve is closed. Oil is pumped into the pressure tank to the test pressure, and the air pressure in the spray chamber is adjusted. All test conditions being obtained, the clutch trip lever is struck. The timing valve opens, allowing oil under high pressure to pass to the injection valve and open it, causing a spray to shoot across the chamber. The cut-off valve then opens after the required time interval, releases the pressure, and causes the injection valve to close and cut off the spray. The timing switch is closed when the timing valve is opened and the condensers are discharged across the gap, a series of 25 pictures being taken of the start, development, and cut-off of the spray.

## Spray Photographs

Fig. 3 shows a complete spray from an injection valve employing medium centrifugal force. The injection pressure was 8000 lb. per sq. in., and the chamber-air pressure was 200 lb. per sq. in. The actual penetration of the moving spray in inches and the time in thousandths of a second from the start of injection are given by the scales. The start of cut-off is marked.

The end of the spray after cut-off appears somewhat like a corkscrew. This spiral appearance is probably caused by whirling of the oil drops which have passed around spiral grooves inside the valve, and seems to continue after the oil has left the valve in spray form. It will be noted that the spray seems to have lost its motion in the last few pictures, especially at the nozzle where the spray is practically hanging motionless in mid-air.

The penetration-time curves are plotted from data computed from measurements of the spray images on each film, taking into account the film speed and photographic reduction as has been done in computing the scales on the above-mentioned pictures. The spray volumes are computed by summation of the differential cylinders making up each spray.

In Fig. 4 are shown non-centrifugal sprays from a cylindrical orifice injected at 8000 lb. per sq. in. pressure into the atmosphere, and into 200 lb. per sq. in. air pressure. The sprays appear somewhat like fir trees with drooping branches. This is because the velocity of the drops of oil is practically zero at the outside of the spray and increases toward the center. The oil seems to shoot out through the center and spill over on the sides, much like a fountain of water. On the sides of the sprays, clouds of oil particles appear as bumps, which do not change their position from one picture to another. They show that the oil particles at the outside of the spray are motionless. The included angle for these sprays was increased 50 per cent by injection into dense air. The atomization also appears to be increased, as shown by the pictures.

High-centrifugal sprays injected into the atmosphere and into 200 lb. per sq. in. air pressure are shown in Fig. 5. The reduction in the spray angle with the spray injected into dense air is about 40 per cent. This may well explain the failure of some centrifugal valves to operate successfully in an engine when the spray appeared well suited for the engine combustion chamber from observations made in the atmosphere. This decrease of spray-cone angle is characteristic of all centrifugal sprays.

In Fig. 6 are two sprays, injected into 200 lb. per sq. in. air pressure, which show what might be called scale effect; that is to say, the ratio of orifice area to groove area is the same for both, but a larger orifice and grooves were used for the second spray, and as a result the quantity of oil injected was nearly three times as great.

Fig. 7 shows a spray which has a small secondary spray dis-

charge taking place after cut-off. This phenomenon is thought to be caused by a pressure wave in the oil line, and was eliminated in the second series of pictures by increasing the length of the injection-valve tube, thus damping out the pressure wave because of the increased friction and greater oil volume.

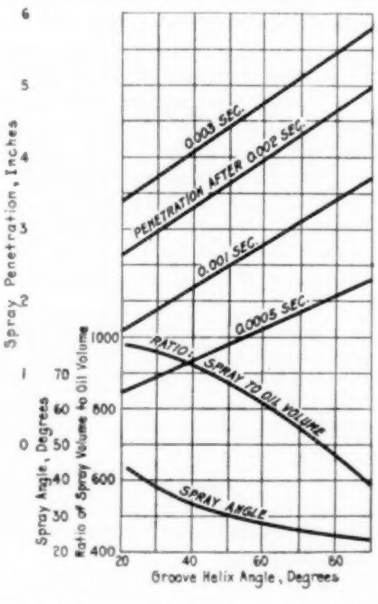


FIG. 11 EFFECT OF GROOVE HELIX ANGLE ON SPRAY CHARACTERISTICS

(Injection-valve No. 7; 0.022 in. diam. orifice; injection pressure, 8000 lb. per sq. in.; fuel oil used, Diesel oil of 0.85 specific gravity; gas in spray chamber, nitrogen at 200 lb. per sq. in.)

### EFFECT OF INJECTION PRESSURE

Fig. 8 shows the effect of injection pressures of from 2000 to 8000 lb. per sq. in. on the penetration of sprays, from a 0.0155-in.-diameter round orifice, injected into 200 lb. per sq. in. air pressure. The curves are almost straight and parallel, which shows that the penetration increased nearly in proportion to the injection pressure. This is a characteristic result. There is of course a limit beyond which increase in the injection pressure would not increase the penetration and might even decrease it. This limit is reached when the drops are atomized so finely as to be too light to penetrate the dense air. The injection pressure affects the spray-cone angle as well as the penetration. Increase in the injection pressure causes a narrower spray-cone angle with a non-centrifugal valve, and a wider spray-cone angle with a high-centrifugal valve.

### EFFECT OF GAS DENSITY

Fig. 9 shows the effect of chamber-gas pressure and density upon the spray penetration after 0.001, 0.002, and 0.003 sec. The main curves were cross-plotted from the curves shown in the insert, which are for nitrogen gas, and from similar curves obtained with helium and carbon dioxide gas in the chamber. Each point is labeled as to the gas which was used in obtaining it. The points obtained by injection into the various gases were all plotted on a basis of absolute gas density. As all of the points lie on the curves, this shows that it is the absolute density of the gas which controls spray penetration, that the viscosity of the gases has no appreciable effect, and pressure affects the penetration only in so far as it controls the density. This indicates that it is the density of the gas in the engine which controls spray penetration in an engine cylinder, and not the compression pressure.

### EFFECT OF SPECIFIC GRAVITY OF FUEL OIL

Fig. 10 shows the effect of the specific gravity of the fuel used upon the spray penetration after 0.001, 0.002, 0.003, and 0.004 sec., with a high-centrifugal valve spraying into 200 lb. per sq. in. chamber pressure. The points for the curves were cross-plotted from the curves for heavy fuel oil shown in the insert, and from similar curves for the other fuel oils.

The penetration is seen to increase with the specific gravity and from the upward trend of the curves; oils of greater specific gravity than those tested would have still greater effects. From the curves, a heavy oil of 0.90 sp. gr. would have 10 per cent greater penetration after 0.003 sec. than an ordinary Diesel oil of a sp. gr. of 0.85. The heavy oil is more viscous than the others, and is not as readily atomized. This makes the spray angle narrower and helps to produce greater penetration.

### EFFECT OF VALVE DESIGN

The effect of the groove helix angle on the penetration, cone angle, and ratio of spray volume to oil volume with a valve injecting into 200 lb. per sq. in. air pressure is shown in Fig. 11. The penetration increases considerably with increase in the angle of the spiral grooves, the 90 deg. or non-centrifugal spray having 60 per cent greater penetration after 0.003 sec. than does the 23-deg. high-centrifugal spray. The spray angle was decreased from 53 deg. to 23 deg. by this same increase in the groove helix angle.

To find the relative distribution, and to obtain an indication of the atomization of the spray, the actual spray volumes were computed. The quantities of oil injected with each valve set-up

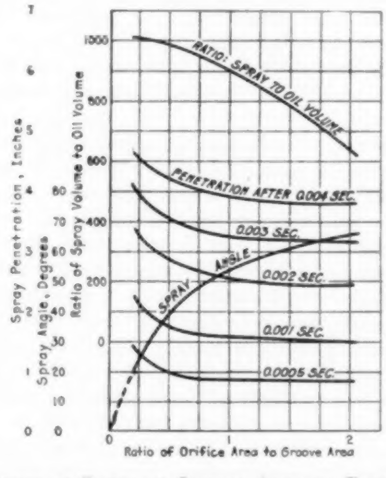


FIG. 12 EFFECT OF RATIO OF ORIFICE AREA TO GROOVE AREA ON SPRAY CHARACTERISTICS

(Injection valve No. 7; 23-deg. spiral grooves; 0.012, 0.022, and 0.040 in. diam. orifices; injection pressure, 8000 lb. per sq. in.; fuel used, Diesel oil of 0.85 specific gravity; nitrogen in spray chamber at 200 lb. per sq. in.)

were, however, different, so in order to put them all on the same basis, the ratios of spray volume to oil volume were computed. These are plotted in Fig. 11 and indicate the spray distribution. The distribution was 100 per cent greater for the high-centrifugal than for the non-centrifugal spray.

The effects of varying the ratio of orifice area to groove area from 0.19 to 2.05 upon the spray penetration, cone angle, and the ratio of spray volume to oil volume, with 200 lb. per sq. in. air pressure are shown in Fig. 12. The penetration increases rapidly as the ratio becomes very small. The ratio was decreased by decreasing the size of the orifice, the groove area being kept constant. Thus the orifice became very small with a small ratio and the rotation of the jet initiated by the spiral grooves

could not continue effectively, through this small orifice. The energy which with a larger orifice was consumed in rotating the oil, went into giving the spray axial penetration in the case of the very small orifice. The spray angle was therefore reduced, and this is shown by the spray-angle curve. The shape of this curve seems to indicate that the spray angle would not be greatly increased by increase in the ratio beyond 2.0.

The curve at the top of the sheet shows the effect of the ratio of orifice area to groove area upon the spray distribution. This curve would seem to indicate that the orifice size has considerable effect upon the spray distribution and possible atomization.

### Conclusions

The test results presented in this paper are examples of the information which it is possible to obtain by means of the spray-photography apparatus described. The results show some fundamental effects of injection pressure, chamber pressure, specific gravity of the fuel oil used, and valve design upon oil-spray characteristics. By means of such investigations, data are obtained which make possible the design of injection valves to produce sprays for various sizes or shapes of engine combustion chambers.

## Discussion

Robertson Mathews.[2] The success attained by the National Advisory Committee for Aeronautics in photographing oil sprays in a manner that reveals the spread and penetration of the jets from different types of nozzles, will be followed, it is hoped, by the obtaining of like information on the magnitude and interval of that more illusive phase of solid injection to which we apply the somewhat broad term "dribbling." Pictures of jet dribbling should be worth while even though they do no more, for the time being, than lead to a more specific definition of the term.

There is much concern among many engineers over the effect of dribbling upon fuel economy. Much effort has been expended on the design of pumps to reduce dribbling. Since the end is probably the most difficult phase of injection to control, photographic evidence of the characteristics of that phase would seem to deserve equal, if not more, attention than the initial discharge.

Paper targets have revealed that for a given nozzle and pump there are certain fuel quantities and r.p.m. that give the most uniform discharge, with a smaller percentage of the injection interval consumed in nozzle-closing effects. The determination of the variations in discharge characteristics with r.p.m. should aid in the development of greater engine flexibility.

Regarding the extent to which such photographs can be used to aid in developing combustion-chamber design, an early decision may lead us astray. Much stress is laid today upon turbulence. We should like to observe how a stream of air of a density corresponding to 300 lb. abs. and 800 deg. fahr. may be able to bend or divert the spray. It would not call for much change in the equipment to connect to the spray chamber an air loop with a spring-actuated piston to alter the location of the air, or of an inert gas, in the loop and chamber during injection.

There is a growing opinion that we must get nearer to the actual operating phases in order to obtain trustworthy information bearing on engine-cylinder design. We should like to see the N.A.C.A. develop for their experimental engine a glass cylinder, or else something like Ricardo's quartz windows. Then the present photographic equipment could be applied together with suitable additions to catch a picture of the inflammation of the charge. There is a tendency among jet investigators to overlook the possibility of combustion wiping out the crest of jet before the injection is completed.

[2] 1248 Newport Ave., Detroit, Mich.

O. E. Jorgensen.[3] Our knowledge of fuel-oil sprays has been limited to what we could observe in the open air, and any one has been free to imagine what effect the greater density of the air in the compression space of a Diesel engine might have on them. The experiments recorded in the paper have removed this uncertainty and will assist experimenters in this field in visualizing more exactly and truly what actually takes place inside the cylinder, at least during the injection period.

In connection with development work on two-cycle solid-injection Diesel engines using high fuel-oil pressures, a number of observations of sprays were made last summer in Worthington Pump and Machinery Corporation's Buffalo Works, and even though these experiments were limited to the open air, some of the results obtained may be of sufficient general interest to justify mention.

Arrangements were made to motor the engine with its fuel-oil pump at engine speed (400 r.p.m.); the fuel spray valve could be fastened to a bracket at the side of the flywheel so that the spray would shoot straight across the outer cylindrical surface of the wheel and by the trace of oil left on the wheel give information on the following conditions:

*a* The time lag between the beginning of the discharge stroke and the beginning of the discharge from the spray valve, which was found largely to depend on the volume of oil contained in the pump and the discharge line.

*b* The location of the dead center in relation to the actual beginning of the injection.

*c* The actual end of the injection for any load carried by the engine, which was regulated by a hand-operated handle.

*d* The function of the fuel spray valve and fuel-oil pump, especially their ability to produce a spray starting sharply and terminating suddenly without any dripping. When the functioning had been perfected, the picture left on the flywheel was an area thickly coated with fuel oil and confined between two straight, sharp lines marking the beginning and end of the injection and located on the wheel at an angle with the center line of the spray valve which disclosed the velocity of the jet, or, as it is called in this paper, the penetration.

In one experiment the nozzle diameter was 0.00135 in., the fuel oil pressure about 5000 lb., the flywheel diameter 25 in., the speed 400 r.p.m., the fuel light Diesel oil, and no centrifugal action was employed. In this case the jet traversed the 6-in.-wide wheel in the time required for the wheel to advance 1 in., which means that the jet velocity was six times as great as the rim velocity or 260 ft. per sec. In the terms used in the paper, the penetration in 0.002 sec. is 6.2 in.

It is interesting to compare this result with those given in the paper. The nozzle was of the type used for the experiments given in Fig. 8, for which a penetration into an atmosphere of 200 lb. is found equal to $3^3/_4$ in. Fig. 9 shows the effects of density of the atmosphere and gives $3^3/_4$ in. for atmospheric pressure, but only $2^3/_4$ in. when the air pressure is 215 lb. abs. Increased in this ratio the penetration of the Fig. 8 jet into open air would be 5.1 in. as against 6.2 in. found by the flywheel method. These two values are close enough to demonstrate the merits of this method of experimentation, and had the determination of the penetration been the main object of the test it would have been an easy matter to determine it more exactly, namely, by making a correction for the spread of the fuel-oil jet, which has an effect on the lines drawn on the flywheel tending to give too high a value of the penetration.

[3] Worthington Pump and Machinery Corporation, New York, N. Y. Mem. A.S.M.E.

In closing, the writer would ask why it is that the penetration found in Fig. 9 for 215 lb. abs. pressure is not the same as the one found in Fig. 10 for fuel oil of 0.85 specific gravity, as all conditions recorded for the two experiments in that case would seem to be alike. The penetrations are respectively $3^1/_2$ in. and $4^1/_4$ in. in 0.003 sec.

P. H. Schweitzer.[4] It may not seem evident to many, but the author's paper has for its direct object methods for making oil engines lighter, safer, and more economical.

In the last twelve months we have witnessed heroic efforts and a number of failures in attempts to cross the Atlantic in an airplane. A year ago Captain Fonck's Sikorsky plane exploded when it tried to hop off with the heavy load. The plane burned and the accident took two lives. With engines using non-volatile oil instead of volatile and explosive gasoline that fatality might have been avoided. Captains Davis and Noel were killed because their plane was unable to lift safely the weight of the fuel. The French fliers Nungesser and Coli decided to omit radio from their equipment because they needed all of the lifting power for fuel. A radio sending apparatus might have saved their lives. Present-day oil engines consume about 0.4 lb. per hp-hr., while gasoline engines use more than 0.5 lb. Twenty per cent of the fuel, i.e., more than 1000 lb., could have been saved with oil engines and the spare lifting power used for radio equipment, stronger fuselage construction, etc. if the development of the high-speed oil engine had reached the stage which we hope it will reach in five or ten years from now and which will permit their safe application in airplanes.

The National Advisory Committee at Langley Field is doing more for such development than any other organization in the world, and the present paper is a fine example of their activities.

Information regarding the characteristics of oil sprays when injected into a chamber filled with high-pressure air or gases is very essential for improving the performance of injection oil engines. The Engineering Experiment Station of the Pennsylvania State College has started an investigation of oil sprays for solid-injection engines. This investigation will cover low-speed stationary engines as well as the high-speed automotive engine, and the line of attack differs somewhat from the one described in the paper, which use high-speed photography.

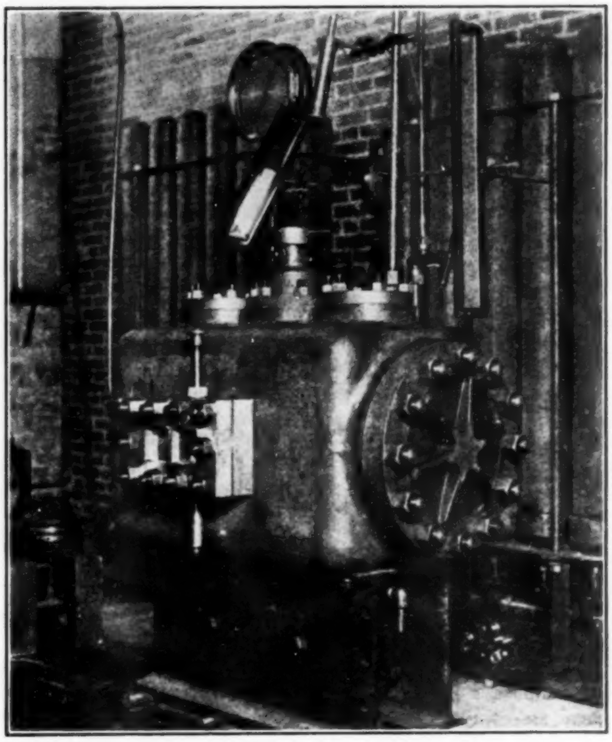

Fig. 14 Pressure Chamber for Use in Fuel-Spray Experiments

Fig. 13 gives an idea of the experimental arrangement adopted, and Fig. 14 shows the pressure chamber.

The pressure chamber is a rectangular casting with 28 × 20 × 20-in. outside dimensions and a 2 to $2^1/_2$-in. wall thickness, tested for 800 lb. hydrostatic pressure. It has two plate-glass windows 1 in. thick, one for observation and one for illumination. The observation window is provided with a window wiper for cleaning off the oil. Illumination is furnished by a 400-watt lamp.

In the study of the penetration energy visual observation is supplemented by a pendulum device (on top of the chamber) which is deflected by the impingement of the spray. The deflection of the pendulum is shown by a light beam reflected by a small mirror attached to the pendulum, and after a second

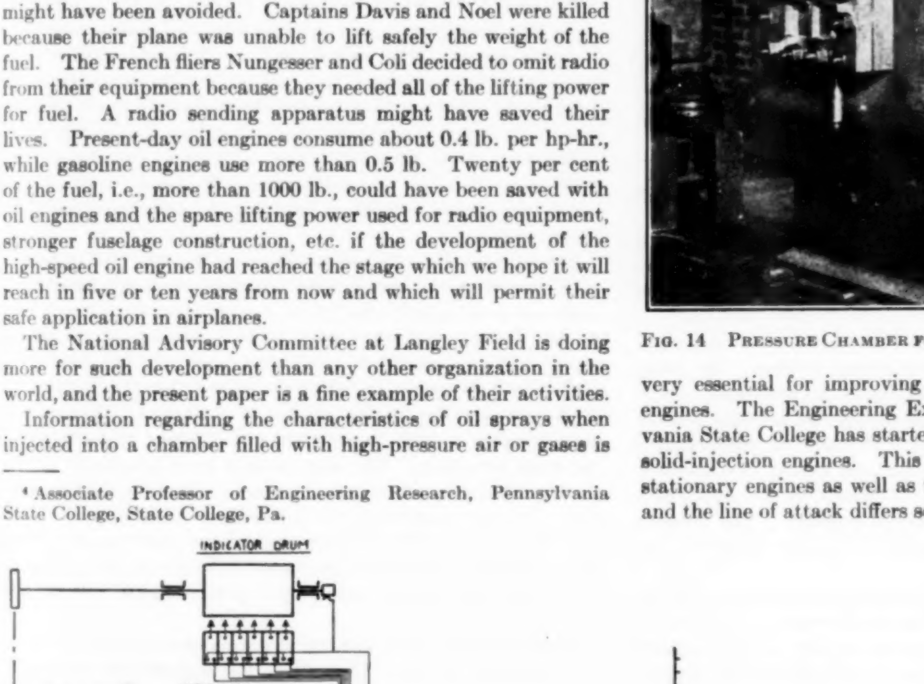


Fig. 13 Diagram of Experimental Equipment at Pennsylvania State College

[4] Associate Professor of Engineering Research, Pennsylvania State College, State College, Pa.

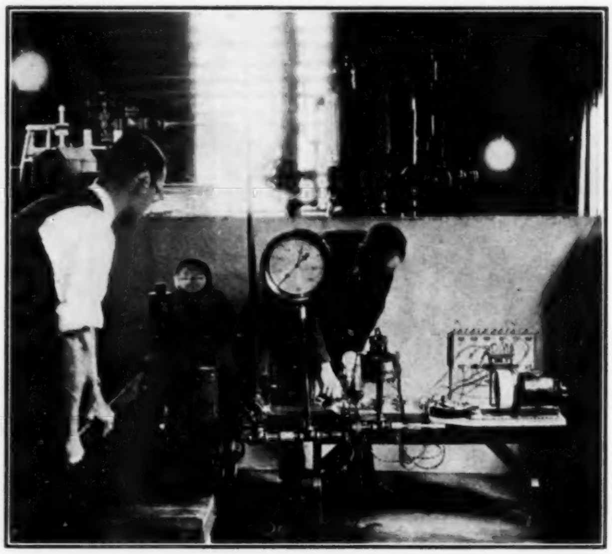

FIG. 15 PRESSURE INDICATOR AND RECORDING APPARATUS

reflection by the long 45-deg. mirror is projected to the screen visible at the right-hand side of the chamber.

The compressed-air line connects the pressure chamber with the air bottles (in the background), which are filled by a four-stage air compressor located in the next room and therefore not visible in the picture.

At the left-hand end of the pressure chamber the injection nozzles are mounted in adjustable nozzle holders. By using spacers the distance from the nozzle tip to the pendulum can be varied. Injection both by automatic and by cam-actuated nozzles is studied. The standard experimental nozzle is cam-actuated and the oil pressure is maintained uniform during the injection. For this purpose an accumulator is placed in the line which prevents a rapid variation of the liquid pressure. The pressure is produced by a hand pump capable of giving 10,000 lb. per sq. in.

In order to produce rapid single injections a control mechanism operates the lever which acts on the needle valve of the nozzle. The fuel cam, while revolving, moves axially and disengages from the roller after one revolution is completed if so desired. In this way not only continuous but intermittent sprays can be studied by one or any number of injections.

When testing automatic injection nozzles, a cam-driven power pump will be used instead of the hand pump.

To record the pressure variations in the injection line during the short time of the injection, a special indicator, Fig. 15, is used.

In preparing for this investigation we were confronted with the problem of recording pressure variations which take place in as short a time as one-hundredth of a second or less, and during which time the pressure rises to several thousand pounds per square inch and drops back almost to zero. Since no instrument seemed to answer these requirements the indicator is shown in Fig. 15, was developed and built in the college shops.

The main principle of the indicator is the use of a number of pressure-registering elements instead of a single one. Each of the six diaphragms is set for a different pressure and at the instant the pressure reaches a predetermined pressure, electric contact is made which is recorded on a rotating drum. The contact is maintained as long as the pressure exceeds the pressure for which the diaphragm is set, and during that time the corresponding spark needle on the drum punctures the paper at each spark, producing a row of holes. In this way a number of lines are produced, the length of each corresponding to the time interval during which the pressure exceeds the pressure for which the respective diaphragm is set. Using six diaphragms, which deflect at, say, 200, 400, 750, 1200, 2000, and 3000 lb. per sq. in. pressure, respectively, we obtain 12 points, 6 for the ascending and 6 for the descending curve, indicating the time at which these pressures were passed during the injection. The connection of these twelve points into a continuous curve giving a time-pressure diagram offers no difficulty. The electrical recording is practically instantaneous, and since the movement of the diaphragms is but a few thousandths of an inch, the inertia effect is negligible.

With this indicator, pressure variations of several thousand pounds within less than one-hundredth of a second have been recorded and time-pressure diagrams obtained.

EDGAR J. KATES.[5] Much interest attaches to Fig. 5, comparing a high-centrifugal spray injected into the atmosphere with the same spray injected into dense air. The reduction in penetration into dense air was to be expected, but the reduction in the spray angle could not be so positively foreseen. Until this was proved by direct experiment, many designers believed that injection into dense air would cause a spray to broaden or disperse more than in the atmosphere. Research work of this sort is exceedingly valuable for ridding the practical mind of its preconceptions.

Referring to Figs. 11 and 12 showing the effect of injection-valve design on the spray characteristics, too much importance ought not be attached to the "ratio of spray volume to oil volume." At first thought this ratio seems to be a measure of the atomization, but as a matter of fact it indicates only the size of the *periphery* of the spray, and does not show either the distribution of the oil particles in the interior or their size. It would be quite possible to have many sprays of different types but with the same periphery. One spray might have practically all the oil concentrated in the exterior surface in the form of large particles. Another might have fine particles on the exterior and larger particles inside. Still another might have particles of uniform size, uniformly distributed throughout the entire spray volume. Obviously these various sprays would perform quite differently in an engine.

There has been some criticism of the elaborate manner in which the National Advisory Committee for Aeronautics has undertaken its research work on oil sprays, but the problems involved are almost limitless and it seems impossible for the research to be made too thorough.

ALAN E. L. CHORLTON.[6] The author in opening his paper seems to have overlooked the large development in the use of injected oil in a self-ignition engine, begun by Akroyd-Stuart lately deceased, but who in his lifetime claimed to have anticipated Diesel—his patent is dated two years earlier—as particularly exemplified in such engines as those of the Lincolnshire type. A vast amount of interesting information can be drawn from development work in this field which would undoubtedly be valuable to investigators at present concerned with similar problems.

The forms of the sprays experimented with by the author do not quite convey themselves to the author in a strictly practical sense. It is essential that a spray shall start with a high degree of sharpness and cease at even a higher rate still—that is to say, that the valve shall seal itself quite tightly and extremely smartly. The percentage effect of dribbles, or loss of oil, absolutely spoils the consumption figures if they are to be good ones. It is there-

[5] Consulting Engineer, New York, N. Y. Mem. A.S.M.E.

[6] Chief Engineer, Wm. Beardmore & Co., Ltd., London, England. Mem. A.S.M.E.

fore necessary to concentrate on sharp mechanical action and not on the spray alone.

The injection pressure should mainly be set up by the orifices themselves, and not by the loading of the needle valve. The writer suggests that the oscilloscope is a good agent for examination in this respect.

THE AUTHOR. Mr. Jorgensen in his discussion mentions a nozzle diameter of 0.00135 in. I am very sure that this should be 0.0135 in. In closing he asks why there is a difference in penetration shown by Fig. 9 and Fig. 10 for what appear to be the same conditions. The reason for this difference is that the lengths of the orifices used were different in each figure. The orifice length in Fig. 9 was 0.058 in. and that used in Fig. 10 was 0.035 in. The orifice length has a considerable effect on the spray characteristics of centrifugal-type injection valves. I refer to N.A.C.A. Report No. 268, entitled "Factors in the Design of Centrifugal Type Injection Valves for Oil Engines," by W. F. Joachim and E. G. Beardsley. This contains a section devoted to the effects of ratio of orifice length to diameter on spray characteristics.

My statement in the paper that Dr. Diesel was the first to build a successful compression-ignition oil engine was based on all the information that I was able to obtain. I am glad that Mr. Chorlton corrected me as to the precedence of Akroyd-Stuart's engine developments.

# Diesel Engines for Locomotives

By R. HILDEBRAND,[1] ST. LOUIS, MO.

*Objections to the steam locomotive are made on grounds of inefficiency, the author stating that 92 to 98 per cent of the heat in the coal is being wasted, while a Diesel locomotive has an efficiency of about 33 per cent. The Diesel locomotive, however, cannot be started under full load, cannot carry any overload without excessive pressures and temperatures, and is so inflexible that an indirect drive or transmission is necessary. The principal objections to the indirect drive are cited by the author, who then makes the proposal of improving the cylinders of the steam locomotive so that they may be used either as steam or Diesel cylinders or as both simultaneously, thus retaining the advantages of both types of engine. An explanation of the working of such an engine is given, and the conditions under which the various combinations of operation are to be used are explained. Typical indicator cards for steam, for Diesel, and for combination operation are given, and the advantages of the system are explained. In closing the author answers a number of questions and objections which naturally present themselves.*

THE subject under discussion will be the outstanding strong and weak points of the steam locomotive and the existing Diesel locomotives. It will be seen that the combination of Diesel and steam power will result in an engine which is apparently superior to either of the two mentioned types.

The steam engine, in some respects, is remarkably well adapted to the requirements of the railroads. It can start under full load and can carry a heavy overload. This makes it practicable to directly drive the axles; thus a steam locomotive with this type of drive is not only very flexible, but is also a simple and cheap engine.

The principal objection to a steam locomotive is its very low efficiency. A switching engine operates with about 2 per cent, and the average main-line locomotives with 6 to 8 per cent total efficiency. Thus, from 92 to 98 per cent of the total coal burned is lost.

The Diesel engine, on the other hand, is the most economical prime mover. It has a thermal efficiency of about 33 per cent, but it is an engine which cannot be started under full load, and which cannot carry a heavy overload without encountering excessively high temperatures and pressures inside of its working cylinders. Lacking sufficient flexibility, it has not yet become practicable to drive the axles *directly* by Diesel power. All present successful Diesel locomotives use some kind of indirect drive or transmission between the Diesel and the axles. Numerous kinds of transmission have been tried, the electric drive being the most popular one. It requires, in addition to the engine, an electric generator or a hydraulic pump or a compressor, depending on the type of transmission, and a corresponding electric, hydraulic, or gas motor. The principal objections to the indirect drive are as follows:

The total weight of the locomotive should not overstep certain limits, because the existing road beds, bridges, etc. cannot stand an excessive load. In order that the total weight of the locomotive may remain within customary limits, which are about 160 lb. per hp., its engine plus its drive should not exceed a certain weight. As all indirect drives are heavy, particularly the electric type, the engine proper should not weigh more than 50 to 60 lb. per b.hp. This weight is too light for the heavy-duty service which is required by the railroads.

The term "heavy duty" means that the engine can be used for a greater length of time without being completely overhauled. This is impossible with light-weight engines, as the designer is forced to use high rotary speed, and to push the working cylinders as closely together as practical. This results in high cylinder wear and short bearings, and consequently high bearing wear.

The high wear and tear of engines of this kind is sufficiently proved by submarine engines, which also weigh 50 to 60 lb. per b.hp. For submarines, however, the initial and maintenance costs are of secondary importance, while the deciding factor for railroads is first of all the commercial result. For railroads, the high initial and maintenance costs of the present Diesel-electric locomotive, or other Diesel locomotives with indirect drive, will be a great handicap.

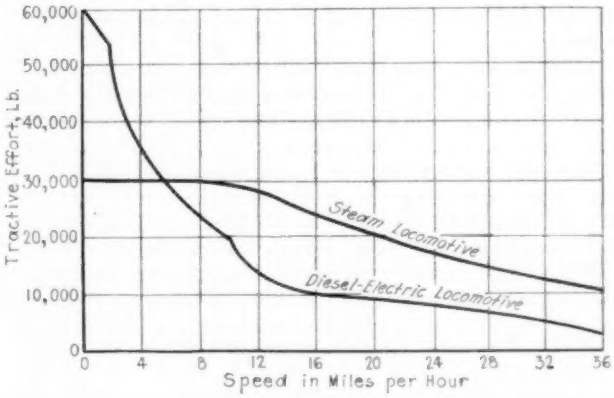


FIG. 1 TRACTIVE EFFORT OF THE DIESEL-ELECTRIC AND OF THE STEAM LOCOMOTIVE

Furthermore, the indirect drive, whether it is electric, hydraulic, or gaseous, has a low mechanical efficiency. For instance, the electric transmission has about 65 to 85 per cent mechanical efficiency, depending on the load and speed.

Also undesirable are the peculiar speed-tractive-effort characteristics of locomotives using Diesels as prime movers which drive by means of any of the indirect power transmissions. These characteristics differ much from those obtained with steam locomotives.

This is illustrated in Fig. 1, which shows the tractive effort of the Diesel-electric and of a steam locomotive. The former has a very favorable tractive effort during starting, but it drops off very rapidly when the speed increases. Thus the Diesel-electric locomotive is well adapted for switching because it can quickly accelerate a heavy train. However, for main-line engines the steam locomotive furnishes a much more desirable tractive effort at higher speeds.

The above-mentioned strong and weak points of the present Diesel locomotives are fundamental. These being facts, it appears that the present Diesel, in spite of its very desirable thermal efficiency, is a prime mover which leaves much to be desired for main-line service.

With due respect to all the accomplishments in Diesel loco-

[1] Chief Engineer, Diesel Department, Fulton Iron Works Co., St. Louis, Mo.

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motives, it is the author's personal opinion that for main-line locomotives the present Diesel, in connection with any of the existing indirect drives, is not the final solution of the problem. It appears to be a move in the wrong direction to completely abandon the present steam locomotive, which has proved so successful during the last one hundred years, and which adapts itself remarkably well to the requirements of the railroads besides being very simple and cheap. It seems to be logical to combine, at least for main-line purposes, the Diesel and steam power, to adhere to the direct drive, and to take advantage of the high thermal efficiency of the former and the great flexibility and adaptability of the latter.

### The Diesel-Steam Locomotive

What the author proposes is not to abandon but to improve the steam locomotive with its direct drive by changing its working cylinders so that they may be used either as a Diesel or as a steam engine, or simultaneously as a Diesel-steam engine. The combination of the Diesel and steam power could be called the Diesel-steam engine. However, to distinguish the engine which the author proposes from the existing well-known "Still" engine, which is also a Diesel-steam engine, the author's engine will be called hereafter the D-H (Diesel-Hildebrand) engine or locomotive.

During starting, only steam will be used. Fig. 2 shows a starting card which is identical with that of a uniflow steam engine. Starting with steam, the D-H locomotive will have same powerful starting ability as the existing steam locomotive.

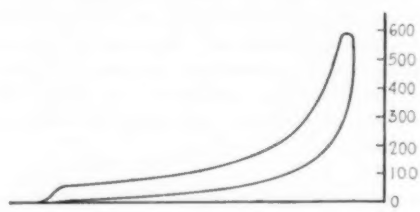
When the engine runs with normal speed and the *average* load, Diesel power only will move the train, and its indicator card will resemble that of Fig. 3. The locomotive while using Diesel power only will operate with a thermal efficiency which is in the neighborhood of 33 per cent and with a mechanical efficiency of about 84 per cent, as the axles are directly driven, and the engine will be of the double-acting two-cycle type. These are efficiencies which none of the existing Diesel locomotives possess.

While climbing steep grades, the D-H locomotive will use Diesel plus steam power. When steam is used in addition to Diesel power the steam will be admitted into the cylinders after the combustion of fuel is substantially completed, and after the gases are expanded to a pressure which about equals the steam pressure. The indicator card while using Diesel and steam power will appear similar to that shown in Fig. 4. The cut-off chosen in Fig. 4 admits just sufficient steam so the auxiliary steam power (shaded area) increases the Diesel power by 100 per cent.

The admission of steam into the power cylinders will begin when the load begins to exceed the *average* one, i.e., when the normal Diesel rating of the engine is reached and overstepped. The steam will then carry the load above that which can be carried by Diesel power. Thus the Diesel power will be used to its fullest extent, and the cut-off of the steam will be chosen to carry the overload.

To fully comprehend the power requirements of a locomotive reference may be made to the power requirements of an automobile. When automobiling, it comparatively seldom occurs that the engine is used to its fullest capacity. After climbing a hill, down again it goes, using little or no power. When passing villages, crossing bridges, short curves, etc. the speed and consequently the power must be reduced. Thus, the *average* power demand on the engine is comparatively low and fluctuates between wide limits. As in automobiling, so in railroad service, the *average* demand on the engine is only in the neighborhood of, say, 50 to 75 per cent of the maximum, depending upon the service and the nature of the road. With working cylinders of just sufficient volume to develop enough Diesel power to meet the said *average* power demand, the D-H locomotive will operate as a pure Diesel most of the time.

As the power cylinders will be dimensioned for the *average* power demand, the D-H engine will have the highest possible thermal efficiency while running under the average load. This thermal efficiency, at the *average* power demand, will be decidedly higher than that now obtained with any Diesel locomotives because their Diesel engines must be dimensioned to suit the maximum power demand, which is undesirably large for the average load.

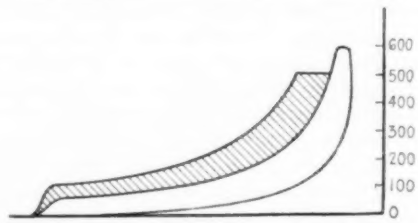




Fig. 2 Indicator Card of D-H Locomotive Under Starting Conditions

Fig. 3 Indicator Card of D-H Locomotive Operating Under Full Diesel Power

Fig. 4 Indicator Card of D-H Locomotive Using Both Diesel and Steam Power

Admission of the steam into the Diesel cylinder, and mixing it with the hot gases therein, will prevent dangerous overheating of the power cylinders because the steam, even if superheated, will have a cooling effect on the hot combustion chambers. The higher the load, the greater will be the quantity of steam admitted, and the more effective will be the internal cooling of the combustion chamber.

The mixing of the steam with the hot gases inside of the power cylinders will result in a heat exchange between the steam and the gases. The hot gases will be cooled to a certain extent, as just mentioned, and the entering steam will be heated (superheated). Thus there will be no loss of heat because all the heat contained in the Diesel gases remains in the cylinder. However, adding steam will increase the heat carried away by the exhaust, thereby reducing the thermal efficiency, although the steam consumption per steam horsepower-hour is a very favorable one. A thermodynamic calculation shows that the steam consumption of the D-H locomotive will be at least as low as that of the compound steam engine when it operates at its most favorable cut-off. This will be the case while the D-H locomotive operates at its most unfavorable cut-off, i.e., when it carries a 100 per cent overload over its Diesel rating. On request the author will gladly furnish these calculations, which

are here omitted because they would make this paper undesirably long.

The explanation for this favorable steam consumption is to be found in the fact that no steam whatever will condense when it enters the power cylinders. On the contrary, as stated, the steam will superheat when it mixes with the hot Diesel gases. The fact is that the steam will still be superheated when it is exhausted into the atmosphere.

From the above it appears, when comparing the D-H locomotive with a locomotive having large cylinders of sufficient capacity to meet the maximum demand by Diesel power, that the thermal efficiency of the D-H locomotive is higher at loads up to the average and lower at loads above the average. Thus, it can be expected that the thermal efficiency of the two compared

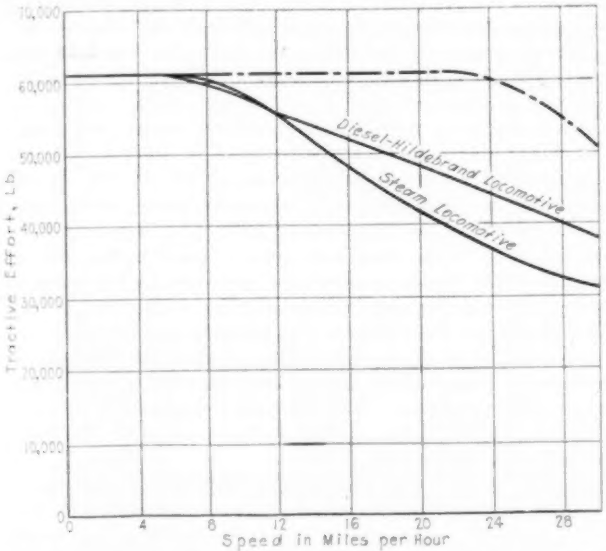



Fig. 5 Tractive Effort of Freight Steam Engine and D-H Locomotive Using Combined Diesel and Steam Power

locomotives is about at par. However, the D-H locomotive will have a much higher mechanical efficiency and also the advantage that it eliminates the indirect drive, and is well adapted for main-line service.

### Comparison of Diesel-Steam Locomotive with Still Locomotive

Here it may be of interest to compare the D-H locomotive with the Still locomotive. The latter type of locomotive is under construction in England and France while stationary Still engines have been in actual service for some time and have proved satisfactory. The Diesel-steam locomotive of the Still type drives the axles directly by means of one set of reduction gears, eliminating the disadvantages of the indirect drive. This is a distinct feature of the Still locomotive, and its results will be watched with keen interest by the railroads.

It will be remembered that the Still is a double-acting engine. Its head end is used exclusively for developing Diesel power and its crank end is used for developing steam power. Therefore the Still is a single-acting Diesel and a single acting steam engine. The Diesel economy is confined to the head end, and the overload-carrying capacity is confined to the crank end. The D-H engine is also double-acting, but it develops Diesel power (high efficiency) and steam power (high overload-carrying capacity) on both sides of the piston. Thus the D-H locomotive with the same cylinder volume as the Still locomotive will have about twice the starting and overload-carrying capacity. The D-H locomotive will therefore adapt itself better to the requirements of railroads than the Still locomotive.

Furthermore, the steam in the Still engine expands in the cool and unsuited crank ends of the working cylinders. With the exception of starting or climbing steep grades, the steam ends of the working cylinders of the Still engine will use short cut-offs which, in connection with cool cylinders, are bound to result in a high steam consumption per steam horsepower-hour. In the D-H locomotive the steam expands under the most favorable conditions, i.e., in hot Diesel cylinders. In consequence, its steam consumption is exceptionally favorable, and it decreases with decrease of cut-off. From this it appears that the steam economy of the D-H locomotive will also be higher than that of the Still locomotive. It will also be of interest to compare the D-H locomotive with the existing steam engine. We shall assume a D-H locomotive of 1400 Diesel hp. at a speed of 24 miles per hour; and we shall assume a freight steam engine of the 2-8-2 type with 27-in. by 32-in. cylinders, and a maximum tractive effort of about 60,000 lb. We shall further assume that the boiler capacity of the D-H locomotive is 60 per cent of the boiler capacity of the freight steam engine. Fig. 5 shows the tractive efforts of the freight steam engine and that of the D-H locomotive when using combined Diesel and steam power. Fig. 5 further shows, by a dash-and dot line, the tractive effort which the D-H locomotive would have provided its boiler capacity equaled the boiler capacity of the steam freight engine.

### Questions as to Practicability of Diesel-Steam Locomotive Answered

Probably several questions will have arisen in the reader's mind; these will be answered as follows:

1 Will the steam which mixes with the products of combustion cause an undesirable chemical effect (corrosion) on the cylinder walls?

In an ordinary Diesel, the products of combustion contain a considerable amount of steam (caused by the hydrogen and hydrocarbons in the fuel oil) which does not affect the cylinder walls whatever.

Another proof that the steam and the products of combustion in the proposed D-H locomotive will not cause difficulties is furnished by the performance of the Still engine. In this engine, while the piston travels, gases will blow by the piston into the steam space because no piston holds perfectly tight, and many leak badly. This brings the steam part of the cylinder liner in contact with the gases. According to the author's knowledge this has caused no piston and liner difficulties, although the crank end of the cylinder liner in the Still engine will be wet because it is comparatively cool.

The most convincing proof that the admission of steam to the working cylinder of the Diesel will not be harmful are the experiments of Professor Hopkinson[3] in which water was injected into the power cylinder of a producer-gas engine to eliminate the external cooling. The water injection lasted from 30 deg. before to 30 deg. after the crank passed through the firing dead center. The author wishes here to quote Professor Hopkinson's own words: "It (the engine) is giving no trouble at all and has been working regularly for two years, the total time of running being 5000 hours. Anthracite coal is used in the producer, and the coal contains a considerable portion of sulphur, yet there has been no trace of corrosion."

The internal-combustion boiler furnishes a further proof that steam and the products of combustion can be mixed and that this mixture will do no harm to cylinder liners and pistons.

[3] A New Method of Cooling Gas Engines, by Prof. Bertram Hopkinson, *Engineering*, 1913, p. 152.

Reference may be made to a paper read by O. Brunler at a meeting of the Institution of (English) Locomotive Engineers, January 14, 1927. An extract appeared in *The Railway Engineer*, of March, 1927, page 97. In this boiler the combustion takes place in immediate contact with the water, the flame being submerged, and the products of combustion passing through the water. The boiler does not produce pure steam but a steam-gas mixture.

If the internal-combustion boiler can be operated in the manner described, and if water can be injected into a cylinder

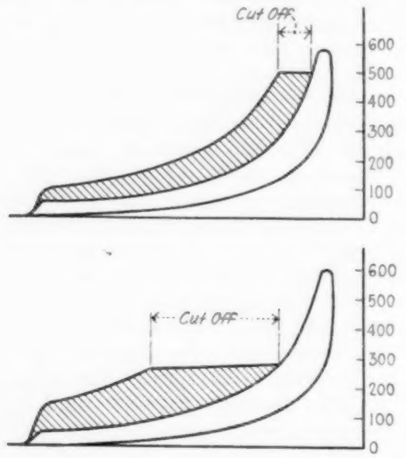



FIG. 6 INDICATOR CARDS SHOWING ADVANTAGE OF HIGH-PRESSURE BOILERS FOR THE D-H TYPE LOCOMOTIVE

of an internal-combustion engine, and if the Still engine is practical, then it is unquestionable that highly superheated steam may be admitted into a hot Diesel cylinder without causing difficulties. There will be no chemical reaction because the highly superheated steam, while expanding together with the hot Diesel gases, will not condense to water. The sulphur dioxide ($SO_2$) contained in the products of combustion cannot change into sulphuric acid ($H_2SO_4$) unless water is present, which, however, will not be the case in the D-H locomotive. The exhaust temperature of the steam-gas mixture, even under the most unfavorable conditions, will be above the point of condensation.

2 Why is the steam to be expanded in the Diesel cylinders and not in separate cylinders?

As the steam will have to do the starting, separate steam cylinders would be of large dimensions in order to furnish the needed starting force. For economy's sake the Diesel should generate as much power as possible (except when starting), leaving little or nothing for the steam cylinders to do. These cylinders would therefore not be doing useful work most of the time but would cause friction losses. It would be uneconomical to generate a small amount of steam power in large cylinders, i.e., to operate them with very short cut-offs. If, however, the steam expands in hot Diesel cylinders, a high economy will be attained, even if only a small amount of steam is needed. Thus for the sake of economy separate cylinders are not desirable. Furthermore, additional cylinders would increase the weight, the unbalanced reciprocating masses, and the first cost; they would complicate the locomotive, and there would hardly be room for them, the Diesel cylinders requiring all the room available.

3 What will be the boiler pressure?

Since the working cylinders must be designed for 550 to 600 lb. initial pressure, it is highly advisable to use also a high boiler pressure, say, 500 lb. gage. Fig. 6 will illustrate this. Both cards show an auxiliary power of just 100 per cent, but the cut-off is much shorter and consequently the economy much greater with the auxiliary power medium of 500 lb. than with the low pressure shown.

4 Will not such a high boiler pressure cause difficulties?

It should not if the boiler is designed for such a pressure. In stationary practice, boiler pressures of 300 to 400 lb. are quite common; also 500 lb. is frequently used. Even 1200-lb. pressures have been successfully tried. All these high-pressure boilers are of the water-tube type. Similar boilers may be installed within the space and weight limits of a D-H locomotive as the boiler capacity required is only about 60 per cent of that which is now used in connection with standard steam locomotives.

5 All high-pressure boilers have small drums and consequently small water contents with only a very limited amount of heat stored up in the water. Will this heat, in connection with the combustion in the boiler, furnish sufficient steam to start and to accelerate the train?

While it is true that the tractive effort required to start a train is great, yet the average engine speed during the starting period is small; consequently, the corresponding horsepower is small. This explains why the limitations on the boiler capacity of the present steam locomotives are mostly felt at higher speeds, while during starting there is ample boiler capacity but not always sufficient adhesion between the wheels and the rails. Therefore a small boiler will be sufficient to start the train and to accelerate it up to a speed of about four miles per hour. After that speed is reached, the Diesel begins to fire and relieves the boiler.

Here it should be mentioned that the D-H locomotive will begin to fire at a lower speed than the ordinary Diesel engine because the former uses superheated steam and the latter cold high-pressure air as a starting medium. Superheated steam heats the cylinders, while the expansion of cold air has a chilling effect which makes starting difficult.

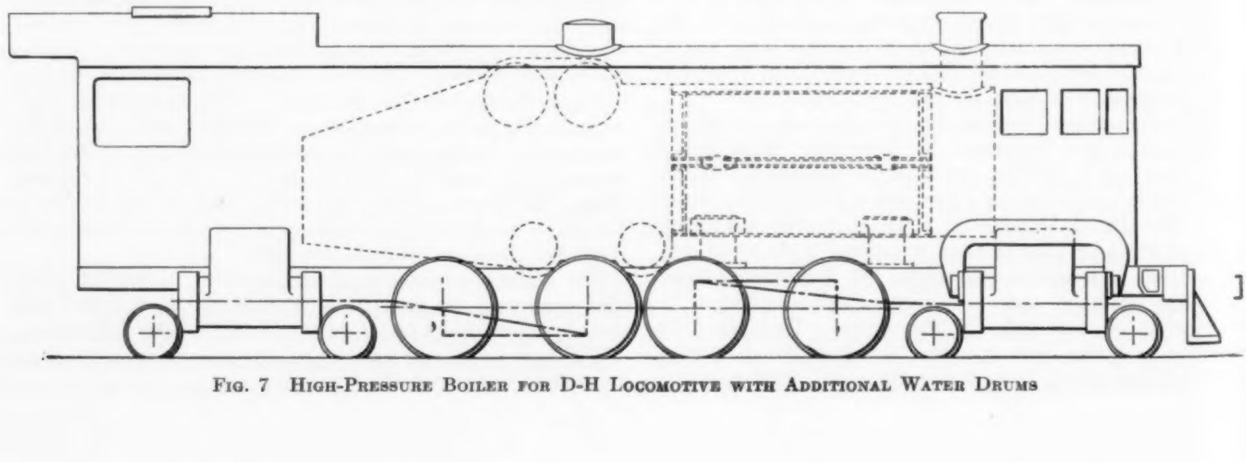


FIG. 7 HIGH-PRESSURE BOILER FOR D-H LOCOMOTIVE WITH ADDITIONAL WATER DRUMS

It should also be considered that the steam consumption, as soon as the firing of the Diesel begins, greatly diminishes not only because Diesel power is added, but because all condensation of the entering steam is positively prevented. Thus, it can be expected that the D-H locomotive will need considerably less steam to start and to accelerate the train than the ordinary steam locomotive, which latter has a comparatively high steam consumption for the power which it develops during the starting period.

There may be conditions when a boiler with a large water volume is desirable, as for instance in mountainous regions. In order to obtain, when conditions demand it, a large water volume, a few additional water drums may be attached to the boiler. A high-pressure boiler with additional water drums is shown in Fig. 7.

6 Will not the cost of maintaining the boiler be a considerable item?

The rate of combustion has a deciding influence on the maintenance of a boiler. While it is true that the boiler of the D-H

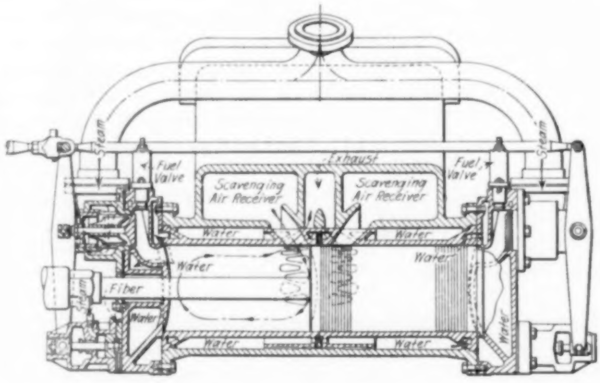



FIG. 8 LONGITUDINAL SECTION OF CYLINDER SHOWING LOOP SCAVENGING SYSTEM

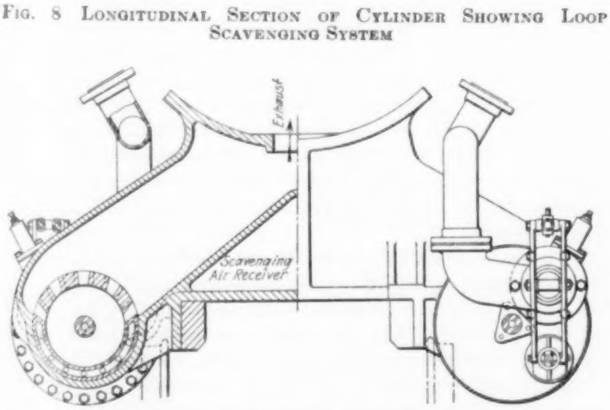



FIG. 9 CROSS-SECTION OF CYLINDER SHOWING LOOP SCAVENGING SYSTEM

locomotive will be kept permanently under full steam pressure to be ready at all times to furnish auxiliary power, steam will nevertheless be used very sparingly, and seldom up to the full boiler capacity. Using Diesel power most of the time, and steam power only intermittently, the cost of maintaining the boiler will be less than that experienced with the present steam locomotives with their high rates of evaporation.

7 What kind of fuel will be used for the boiler?

The most convenient fuel will be the same as that used for the Diesels. If oil or coal dust is used, the fire in the boiler can be instantaneously increased when starting or while climbing a steep grade, provided a small ignition flame burns all the time. Of course, ordinary coal may be used for the boiler. The commercial more than the engineering point of view will decide this question. Here again it should be kept in mind that the locomotive will not burn much fuel in the boiler, because, as stated before, it will run as a pure Diesel most of the time.

8 Why will Diesels of the solid-injection type be used?

It is advisable to use them because injection air would cause too great a chilling effect in the combustion chamber. Consequently, if the Diesel were of the air-injection type, it would require higher speed before the firing would take place than if it were of the airless-injection type.

9 What scavenging-air system will be used?

The loop scavenging system will be found most convenient for locomotive purposes because it permits a long stroke and the arrangement of the exhaust and scavenging ports on the same cylinder side. This arrangement also provides convenient passages for the exhaust and scavenging air. It leaves the lower or bearing halves of horizontal cylinder liners free of ports. This will result in a better cylinder lubrication and a better wearing of the liners and pistons than if the lower cylinder halves were equipped with ports. The loop scavenging system shown in Figs. 8 and 9 has the exhaust and air ports arranged in the upper cylinder half. It has the good feature that its effective stroke (total stroke minus length of ports) is favorable. Also the well-known M.A.M. loop scavenging system will come into consideration; however, here the effective stroke is shorter than in the system shown in Figs. 8 and 9.

10 What kind of valve gear will be used?

The Walschaerts, or any other established reversing gear, may be used. The valve gear has to control only the steam inlet with a variable cut-off. The exhaust and the scavenging air are controlled by the ports. This makes a favorable valve gear.

11 How will the steam inlet valve be made to open just when the gases are expanded to a pressure substantially equal to the steam pressure?

Figs. 8 and 9 will make this clear. These show a preliminary design of a working cylinder and part of the valve gear. The cylinder greatly resembles a uniflow steam cylinder, while the combustion chamber resembles the well-known "A" type Diesels of the former American Diesel Engine Co., which engines have now been in operation for about eighteen years with a record of good combustion.

The valve shown is equipped with a piston at its outer end. The steam pressing on the valve head and its piston, always tends to close the valve and to hold it tight against its seat. The fulcrum of the valve lever is fastened to a small piston, on which the steam presses.

The valve gear tends to open the steam valve slightly ahead of the dead-center position. This (constant) lead is necessary because the locomotive will operate as a uniflow steam engine while starting. When Diesel plus steam power is used, the initial pressure inside of the cylinder rises above the steam pressure. This high pressure will hold the steam valve so tight on its seat that the valve lever fails to open it on account of its yielding fulcrum. The fulcrum will yield until the steam in the cylinder is sufficiently expanded, i.e., until the force to open the steam valve is sufficiently reduced. Then, and not before, will the steam valve open quickly due to the movement of the valve gear and the return movement of the fulcrum by its steam-loaded piston. Selecting a suitable size of the fulcrum piston, the steam valve will open in proper time to obtain a card substantially as shown in Fig. 4. When no steam is used, the steam throttle will not be closed, but the steam on the pistons attached to the fulcrums of the valve levers will be turned off. This will prevent the steam valves from opening.

12 Are the high initial pressures, which are characteristic of the Diesel cycle, permissible in railroad engineering?

To avoid excessive forces, four small cylinders instead of two large ones may be used, as shown in Fig. 7. These small cylinders will drive the axles directly, and their forces will not exceed the piston forces now obtained with ordinary steam locomotives. Consequently, the piston rod, crosshead, connecting rod, pins, and axles will be of the same size as now used in railroad practice.

Instead of using four cylinders, only three or two may be used if they drive through one set of reduction gears as shown in Fig. 10. There is sufficient room to arrange three cylinders within the available space. Using a reduction gear, which only very slightly lowers the mechanical efficiency, a favorable piston speed and a convenient stroke-bore ratio can be chosen.

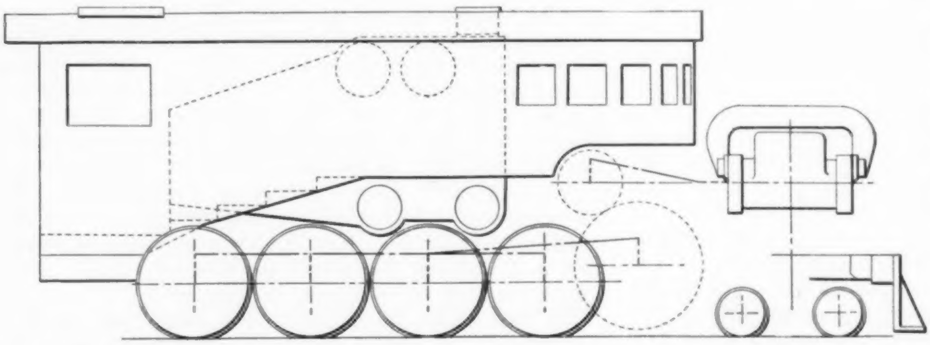


FIG. 10 ARRANGEMENT FOR DRIVING D-H LOCOMOTIVE THROUGH REDUCTION GEARS

13 Are not three or four small cylinders less efficient than two large ones?

It is one of the good features of the Diesel that small cylinders give practically the same thermal efficiency as large ones. So with steam, when it expands in hot Diesel cylinders where no condensation will take place, the cylinder size is of minor importance.

14 Will a three- or four-cylinder locomotive, with its greatly increased reciprocating masses, run just as smoothly as one with only two cylinders?

Using three cranks, the reciprocating masses are balanced more effectively than with only two cranks. When using four cylinders (two on each side, see Fig. 7) and opposed piston travel, perfect balancing of the masses can be obtained, which is impossible if only one cylinder on each side is used.

15 Is it practical to instal a "booster engine" as is done in the standard steam locomotive for raising the tractive effort while starting?

The installation of a booster engine in a D-H locomotive is just as easily accomplished as in a standard steam locomotive because the booster engine may be steam driven.

16 Will it not be quite complicated for the engineer to operate the engine as outlined above?

The whole control on the locomotive will be accomplished by two levers. One will operate the reversing gear in the usual manner. The other lever, when moved into the starting position, will permit steam to enter the cylinders. While this lever is held in the starting position, no fuel will be delivered to the working cylinders. When the control lever is turned into the first notch (i.e., when the Diesel begins to fire) the steam is turned off, and a small amount of fuel will be delivered to the cylinders. Advancing the lever to the next notch increases the fuel supply until the fuel delivery will correspond to the normal Diesel rating of the engine. Advancing the lever still further will begin to admit steam to the cylinders and will increase the fuel delivery until the maximum Diesel rating is reached. The engineer, with this arrangement, can use steam only during starting and when the fuel supply is reached which corresponds to the normal Diesel rating. There is no danger that the D-H locomotive will be operated by steam power alone because it will not have sufficient boiler capacity to be operated satisfactorily.

17 What are the principal disadvantages of the D-H locomotive as compared with the existing engines?

The D-H locomotive has no disadvantages when compared with the steam locomotive. In fact, both types compare very well so far as initial cost, weight, tractive effort, simplicity, and manner of operation are concerned. Their fundamental difference is in the overall efficiency, which will be high with the D-H locomotive and which is very low with the steam locomotive.

The D-H locomotive requires a boiler. This may be considered a disadvantage, while in reality it is a more desirable means for obtaining the needed load on the driving wheels than an indirect drive and other auxiliaries required in connection with the present Diesel locomotives. This refers to main-line engines. It is the boiler with its stored-up energy and with its combustion which is ready at any moment to furnish auxiliary power to the Diesel when starting and when climbing steep grades. It is the boiler which protects the Diesel from being overheated. It is the boiler which enables the engine to furnish tractive efforts which, at all speeds, will be equal to or higher than those of the present steam locomotives. It is the boiler which makes the D-H locomotive adaptable to main-line purposes. On the other hand, it is the indirect drive of the present Diesel locomotive which complicates the engine, causes high initial cost, great total weight, too light an engine for heavy duty, great reduction of the total mechanical efficiency and undesirable tractive efforts at higher speeds. Thus, it is the indirect drive which makes the present Diesel locomotive undesirable for main-line service.

It is unfortunate that the D-H locomotive like the present steam engine must first have its boiler heated in order to be ready for service, and that it will not be smokeless unless it uses fuel oil for its boiler. This, however, is of secondary importance compared with the great advantages which the boiler furnishes.

Minor considerations for or against a certain type of locomotive should not cloud the broad viewpoint from which the merits of the different engines should be judged. The present Diesel locomotives are very desirable switching engines. In this respect they will satisfy the need of the railroads. For main-line service the railroads still depend on the uneconomic steam engine. There is little hope that the present Diesel will make a desirable main-line engine for reasons which are fundamental for all internal-combustion engines, as set forth above.

There are about 70,000 steam locomotives in operation in the United States alone; many of them are main-line engines. There is an urgent need for higher economy not only from the viewpoint of the railroads but also from the viewpoint of national economy. Any suggestions to fill this need should receive proper consideration. How the obtaining of a higher commercial efficiency will be accomplished is of secondary importance.

## Discussion

A. Lipetz.[3] The author's proposition of a direct-driven Diesel steam locomotive is of great interest, especially at present when the Still locomotive in England has already been completed and is undergoing tests. If experience with the Still locomotive should prove that the proposition of a combination of Diesel and steam for railway traction is practicable, we may hope to see the D-H locomotive built in this country. However, there are several points to be taken into consideration in connection with such a locomotive, and the remarks which follow are not made in any spirit of criticism but rather with the idea of assisting in further development of the locomotive.

It would be a mistake in considering the use of steam in a locomotive to treat it from the point of view of power instead of tractive effort. The author's remark that "with working cylinders of just sufficient volume to develop enough Diesel power to meet the said average power demand, the D-H locomotive will operate as a pure Diesel most of the time," is somewhat misleading. A direct-driven Diesel locomotive becomes a constant-torque locomotive instead of a constant-power locomotive as in the case of intermediate transmission. The constant-torque locomotive must be designed to correspond not to the average but to the minimum torque, or a torque very close to minimum; otherwise, for smaller tractive efforts the Diesel engine will be considerably underloaded and its economy reduced. As the torque variation in a locomotive on account of railroad conditions varies from 1:4 to 1:6, the addition of steam power to Diesel power, which will be required, may go up to 3 to 5 times that of the Diesel. This would turn a Diesel-steam locomotive into a steam locomotive with the addition of Diesel cylinders working all the time, with both oil and steam, contrary to the author's supposition that the locomotive will operate as a pure Diesel most of the time. The efficiency of such a locomotive will correspondingly drop and may not be over 10 to 12 per cent as an average, representing an improvement over a steam locomotive which may not justify the complication and the use of oil when coal is available.

Further, among the limitations imposed upon a locomotive, the maximum piston thrust must be taken into consideration. With the present steels in use, the dimensions of the crankpins in a direct-driven freight locomotive are such that the driving wheels must be larger than they should be for tractive purposes only. If calculations are made on the basis of the maximum permissible piston thrust, the cylinder dimensions cannot exceed for our present conditions 16 in. in view of the high ignition pressure in the Diesel cycle. This would call for at least four cylinders for a medium-size locomotive, and possibly for more than four for larger locomotives. Moreover as the rapid change of pressures in the Diesel cycle, especially at high speeds, gives the effect of explosions, it is very probable that the dimensions of pins, bearings, axles, frames, etc. will have to be increased, or if this should be impossible, the dimensions of the cylinders will have to be further reduced. If now one considers that a two-cycle Diesel engine, as suggested in the paper, cannot give over 60 to 65 lb. per sq. in. mean effective pressure, whereas for starting at least 200 lb. would be necessary for the smaller cylinders, and for running conditions on continuous grades about 160 lb., it becomes evident that the addition of steam power will have to be very substantial, ranging from 200 to 300 per cent of that obtained from the Diesel cycle.

Fig. 5 shows that the tractive effort of a D-H locomotive is higher than that of a steam locomotive, but it does not indicate the fact that while in the steam locomotive any tractive effort below the maximum can be easily obtained by shortening the cut-off and rendering the locomotive more economical, in a Diesel locomotive the opposite is the fact, namely, the efficiency of the locomotive will drop with the decrease of tractive effort obtained from the Diesel cycle. Tests made with the 4-10-2 Diesel locomotive with gear transmission recently built in Germany for Russia, have shown that while at full power the total overall efficiency of the locomotive was 29.3 per cent, it dropped to 8-12 per cent when the load was low,[4] and this may happen on the road quite often.

The author states that Professor Hopkinson's tests in cooling Diesel engines by injecting water into the cylinders instead of jacket cooling have proved that there can be no bad chemical effect from the mixture of steam and gases on cylinder walls. However, this expedient, which has been suggested and tried by various experimenters (Capitaine, Banki, et al.), has never become generally accepted, and all our internal-combustion engines are cooled by outside jackets. The reference, therefore, is not very convincing. Nor can the writer consider as very pertinent the author's reference to the Brunler internal-combustion boiler, as this device is only in its preliminary stage and no practical every-day results with the use of steam and the products of combustion in engine cylinders have so far come to our knowledge. We do not, therefore, know whether this mixture will not affect cylinder liners and pistons in the long run.

In conclusion the writer would say that the distinction which the author draws between his proposition and the Still locomotive is not as pronounced as he thinks. The steam ends of the Still cylinders are fairly hot because they are very close to the internal-combustion ends. Moreover the Still pistons have no cooling and are designed in such a way as to depend upon the cooling by steam on the opposite side. Thus the steam is in turn heated by the combustion gases of the Diesel side and consequently the steam is also highly superheated—possibly not so high as the Hildebrand engine, but sufficiently high to prevent any condensation and to permit good thermal utilization.

The author's assertion that the starting effort in his case would be double that of the Still engine is not exactly to the point because the Still locomotives were designed in such a way as to provide sufficient starting effort. In the two-cycle engine designed by the Schneider Company of Creusot, France, provisions are made for starting by steam in both ends of the cylinders. In the four-cycle design where the total volume of the cylinders is comparatively larger, steam is admitted only to the steam ends as this is sufficient for starting and a larger tractive effort would simply cause the driving wheels to slip. There is, however, one essential difference between the Hildebrand and Still engines, which lies in the fact that the Still engine makes use of the waste heat from the steam jacket and exhaust gases, and steam is generated only in so far as it is necessary for making good use of the waste heat. The normal action of the Still engine is therefore always Diesel and steam, the steam costing nothing, whereas in the Hildebrand engine the normal action of the locomotive is with the Diesel engine only, and any steam which has to be used must be generated in the boiler with a corresponding consumption of fuel. In the Still engine the burners are used only for starting and on very heavy grades, whereas in the Hildebrand engine, the writer is inclined to believe, the burners in the firebox will have to be used most of the time.

The solution offered by the author in answer to No. 11 is very ingenious. The simultaneous action of gas and steam valves is very nicely worked out. The author's proposition as a whole is of great practical value and interest, and the writer believes that

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[4] *Railway Mechanical Engineer*, vol. 101, no. 5, p. 272, Fig. 3.

trials and development work with an engine of this sort in this country should be welcomed.

HERMANN LEMP.[5] The oil locomotive has come to stay and will prove to be the one outstanding advance in railroading where complete electrification is not justified by density of traffic or other compelling motives for its adoption. Any serious attempt, therefore, to give to the oil locomotive the flexibility of the steam locomotive while retaining the high thermal efficiency of the internal-combustion engine must be welcomed.

The proposition of the author is such an attempt and appears to be novel as far as the mingling of high-pressure steam and the Diesel cycle is concerned. The writer has no apprehensions regarding the procedure suggested by the author, having in connection with Mr. Chatain started Diesel engines by hot steam in lieu of compressed air several years ago, and at one time seriously considered the use of an oil-fired flash boiler as a starting means in place of an air compressor. He has further introduced atomized water into the air suction of a solid-fuel-injection engine without deleterious results. While the possibility of intermingling the two cycles is admitted, the efficiency is doubtful and remains to be proved.

The building and maintenance of a water-tube or flash boiler giving 500 lb. per sq. in. for locomotive service is, however, not so simple a proposition as to be brushed lightly aside. It is exactly the boiler of the present steam locomotive which is its weakest link, and which more than anything else limits the availability of the locomotive to—say, at its best and when oil fired—50 per cent of continuous service. Therefore, to still maintain a boiler of 60 per cent the capacity of a regular steam locomotive does not impress the writer as very desirable. A boiler of that capacity will still demand water stations, cinder pits, etc., all of which a pure oil internal-combustion locomotive does not require.

The fear expressed by the author that for railroads the high initial and maintenance costs of the present Diesel-electric locomotives with indirect drive will be a great handicap, is not born out by actual experience.

The maintenance of a steam locomotive varies from 15 to 30 cents per locomotive-mile, while on an average a number of oil-electric locomotives of the A.L.G.E.I.R. type in service in the United States for the past three years show that in spite of the handicap of introducing a new product into new hands and service organizations the maintenance varies from 10 to 15 cents per locomotive-mile, which figure is expected to be reduced to 10 cents per mile.

The first cost of the oil-electric locomotive is offset by its greater availability over the steam locomotive.

A steam locomotive of the conventional design requires a heavier roadbed than, say, an electric locomotive of the same weight on account of the added dynamic loading of rail and the vertical component of the connecting-rod thrust. This amounts to from 50 to 100 per cent. Furthermore, the adhesion is much less than when the drivers are propelled by electric motors. That the weight of the most successful oil-electric locomotive is at present about 250 lb. per hp. and therefore greater than 160 lb. per hp. is admitted, but even with this handicap the fuel economy in hauling of freight and passengers is so far ahead of that of a steam locomotive, varying anywhere from 300 to 400 per cent, that the handicap is not seriously felt.

It must be remembered that this steam-locomotive weight of 160 lb. per hp. does not include the weight of the tender loaded with fuel and water, while the weight of the oil-electric locomotive does include both. When this weight is added to that of the steam locomotive and both are compared on the basis of maximum sustained horsepower, we find that the weight of the steam locomotive is between 220 and 230 lb. per hp. or only 20 lb. less than for oil-electric locomotives designed for main-line work. Switching locomotives are much heavier.

The electric transmission permits distribution of the weights over numerous axles so that as far as the effect on the roadbed is concerned it may be forgotten. In the second place, it must not be overlooked that improvements in the design of oil engines of the solid-fuel-injection type are constantly going on and engines of 25 lb. per hp. are already available, which with increased rotary speed will also reduce the weight and cost of the electric transmission.

History will repeat itself as with the development of the gasoline engine. Fifteen years ago the General Electric motor-car engines of 500 r.p.m. were considered high-speed. Today 1200 r.p.m. is accepted as practical, and in automobile and aviation engines 2000 to 3000 r.p.m. is coming more and more into use.

The writer is unable to agree with the author's statement that the characteristics of an oil-electric locomotive and a steam locomotive are fundamentally different as shown in the tractive-effort curves of Fig. 1 of the paper. The locomotives therein compared are evidently of different powers. The steam locomotive has approximately twice the horsepower of the oil-electric. The steam locomotive cannot make use of the full horsepower at slow speed, and only reaches its full power toward the full speed. The oil-electric locomotive, on the contrary, uses its full power over nearly its full range. Hence we are able to do the slow-speed yard shifting (when high speeds are not only undesirable but not practical) with an oil engine of approximately half the horsepower of the steamer.

The Chicago & Northwestern Railway is now using three 60-ton oil-electric locomotives to do yard shifting. Each of these locomotives of 300 hp. working continuously from Monday morning till Saturday night with three 8-hour-shift crews replaces two steam locomotives of 600 hp. each. Actual experience has shown that the three locomotives during 23,084 hours have given a 97 per cent availability and 17,833 hours of actual service, there being no assigned work on Sundays and holidays, which time is included in the 23,084 hours.

The author concedes the possible use of electric transmission for yard shifting, but doubts its adaptability to main-line work. Referring to Fig. 1, it is evident that by changing the gearing of the motor drive the tractive effort at the start may be lessened and higher speeds made possible, and particularly so when the same horsepowers are used in either case. On the contrary, it is the writer's belief that the real field of the oil-electric locomotive will be heavy main-line work where its low fuel consumption and greater availability are the chief economic factors.

Multiple high-speed oil-engine generator units make for reliability of operation, lower costs through mass production, single-crew operation of multiple power plants, and finally a simplicity of control self-adjustable to all load conditions which is hard to achieve through any other transmission means.

In connection with main-line work, an article appeared in *Railway Age* of Nov. 5, 1927, describing a run made on October 13 by a 100-ton oil-electric locomotive, geared for high speed, over the Erie Railroad, from Hornell, N. Y., to Meadville, Pa. The train was run by Erie Railroad officials through two divisions, requiring two engineers. Distance, 183.7 miles; trailing load, four passenger coaches; total load, 280.5 tons. The train ran on express schedule between the two stations, making six station stops of three minutes each. Maximum speed, 56 m.p.h., average speed 33.4 m.p.h., average load factor on oil engines, 49.9; maximum load factor on oil engines, 78.8. Total gallons

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of fuel consumed, 134 (at 5 cents per gal.); total gallons of lubricating oil consumed, 2 (at 50 cents per gal.); total water consumed, negligible; total cost of fuel and lubricating oil for run, $7.70 or per 1.05 cents per car-mile.

The significant thing of this trip was the fact that two steam engineers, who never before were aboard an oil-electric locomotive, took charge and with only five minutes of instructions operated the train (without further help) on a steam-road schedule through their respective divisions.

The citing of this actual main-line high-speed performance, the first in America with an oil-electric locomotive, was prompted by the author's apparent disbelief in electric transmission. In that attitude he is one of many engineers, and out of this praiseworthy engineering competition the most suitable oil locomotive will be evolved. Personally the writer will watch with interest the advent of the English Still locomotive, which he understands will come to test sometime next spring, and hopes that the author will someday see the realization of his endeavors.

In the meanwhile oil-electric locomotives of from 2400 to 3000 hp. are serious projects under construction and will be factors in the race for supremacy in railroad operation.

P. H. Schweitzer.[6] In the first part of the paper the author enumerates some objections to the Diesel locomotives using an indirect transmission. The writer agrees with most of them. The statement that the Diesel engine is inferior in flexibility to the steam engine includes two different things: first, the Diesel engine cannot be run economically or at all at a speed materially different from its normal speed; second, the Diesel engine cannot be overloaded to any appreciable degree. So far as the locomotive is concerned, the first deficiency of the Diesel engine can be corrected by some form of variable-speed transmission, but not the second. If we are concerned with the torque alone the writer knows of nothing better than the electric transmission. Because of its high mechanical efficiency at all speeds the tractive efforts obtainable are very high, the drawbar horsepower being almost constant. Referring to Fig. 1, he would ask the author on which basis the comparison has been made. If the steam and the Diesel-electric locomotive are of equal drawbar horsepower, their tractive efforts at normal speed should be equal. But if the tractive effort of the Diesel-electric from 16 miles up is always less than half of that of the steam locomotive, the writer would not call them corresponding sizes.

Weight and first cost are the only objections against the electric drive so far as transmission of power is concerned. However, if a Diesel locomotive had a perfect transmission it would still lack the surplus power available to a steam locomotive of the same rating for climbing steep hills or accelerating a train quickly. Such extra power can only be obtained from a power accumulator.

The steam engine has a power accumulator in the boiler. Other means would be a compressed-air tank or electric accumulators. If with a Diesel engine we wish to equal the maximum drawbar horsepower of a steam locomotive, we have two alternatives: either install a Diesel engine of a size which is capable of delivering, say, 100 per cent more power than the average load would require, or provide some form of power accumulator. The author chooses the second alternative and gives two reasons therefor: first, the combination he proposes is less expensive to build; and second, it is less expensive to run.

The writer has not at hand sufficient data to contest the first statement, but he does question the second. Referring first to the fuel economy, the author states that the thermal efficiency at the average power demand will be decidedly higher than now

[6] Associate Professor of Engineering Research, The Pennsylvania State College, State College, Pa.

obtained with any Diesel locomotives because their Diesel engines must be dimensioned to suit the maximum power demand, which is undesirably large for the average load. The writer cannot agree with this because one of the characteristics of the Diesel engine is that its thermal efficiency on partial load nearly equals and sometimes exceeds that on full load. The reason is that the indicated thermal efficiency actually increases as the load decreases. A good Diesel locomotive, if run at half-load all the time, would have a fuel consumption less than 10 per cent higher than that of a locomotive engine of half the size running all the time on full load. This difference hardly amounts to anything. As to the effect on the engine, the writer would prefer to run an engine continuously on half-load than continuously on full load. The upkeep cost would probably be less, not to speak of the additional upkeep cost of the boiler.

The electric transmission has proved to be good, but it would be rather expensive and heavy for a 3000-hp. main-line locomotive. The writer wonders if by some arrangement the Diesel power could not be split, having, say, 2000 hp. in direct drive and 1000 hp. coupled with an electric transmission. The starting torque of a 1000-hp. d.c. motor would give plenty of tractive effort at low speed to accelerate a heavy train quickly. Near normal speed the (geared) direct drive would do most of the work, but electric transmission for about one-third of the total power would always be available to assist in taking grades and starting trains from standstill.

If experience should prove that electric or all other kinds of indirect drives now being tried are either mechanically or economically infeasible, the arrangement that the writer has called the accumulator system might offer the "solution." The Kitson-Still and Diesel-Hildebrand systems both have a steam boiler, which is just the thing some engineers would like to eliminate from the locomotive. Comparing the two systems, the author's proposal is more ingenious. The expanding of combustion gases and steam in the same cylinder, though daring, seems to be perfectly feasible. The writer sees no reason why the presence of steam should affect the combustion or the cylinder walls unfavorably. The parts that might give difficulties are the very-high-pressure boiler and the steam valve in the cylinder head.

However, the writer has heard good arguments for eliminating the steam boiler altogether, i.e., replacing it with a compressed-air tank. Such a modification of the Kitson-Still system was proposed by Mr. Child of the Baldwin Locomotive Company. In a similar modification for the Hildebrand system, compressed air would be admitted into the cylinder instead of steam after the combustion of the fuel was substantially completed, and the result would be not much different. There would be an air compressor for 500 lb. pressure and a compressed-air tank of sufficient capacity, but the boiler would be eliminated. The question is which is the less desirable.

Harte Cooke.[7] In general with a locomotive there are a few factors which are vital, namely, cost, weight, and tractive-effort curve.

The author's arrangement requires a complete Diesel engine with coolers, etc., so that the locomotive can operate as a Diesel engine when it is approximately up to speed. For starting it requires a complete steam-locomotive equipment with moderate-sized boiler, with the exception of the steam cylinders, using steam in the Diesel cylinders for starting.

Now it would seem that the steam-locomotive arrangement for starting with its tender carrying water and coal, would cost and weigh more than the electrical equipment used in connection

[7] Engineer, McIntosh & Seymour Corp., Auburn, N. Y., Mem. A.S.M.E.

with the Diesel engine. Also under railroad conditions, it is necessary to run at whatever speed the conditions impose at any particular time, and if this speed is a few per cent lower than the maximum speed permissible with the Diesel cylinders, the Diesel output would be less than it would be with Diesel-electric.

It may be that the extra Diesel-electric power to give a total power of the combined steam and Diesel locomotive would weigh less than the boiler with the fuel and water which would be required, or near enough to the same weight so that the higher tractive effort at starting and lower maintenance and lower fuel cost would make the Diesel locomotive more desirable.

R. Eksergian.[8] The author's proposal to increase the m.e.p. of the indicator card, particularly at the lower speeds, by the use of steam where the torque demand is large and thus to do away with the present costly and heavy transmissions, is one worthy of careful consideration and study for all engineers interested in expanding the utility of the Diesel locomotive for railway service. Assuming that the use of steam on the same side of the piston as for the oil combustion can be worked out satisfactorily, the proposed D-H type of engine is distinctly superior to the Still engine both in weight and steam economy.

However, the mechanical features of the two proposed designs from a locomotive aspect offer certain difficulties which the writer here wishes to point out in a very rough way.

For locomotive performance, good thermal performance is entirely secondary to weight efficiency and flexibility in torque variation. The starting requirements necessitate a large torque at starting, while the performance at speed requires maximum horsepower capacity per pound of weight. In addition, the arrangement of wheelbase and trucks is very important for proper tracking, minimum flange wear, etc.

It is well known that increasing the speed of any type of prime mover reduces its weight, though usually at the cost of higher maintenance. The author's first scheme, though eliminating the transmission, materially increases the weight of the engine if we take its effect on the frames, axles, etc. into consideration. With the jackshaft scheme the engine speed is increased, but at the expense of a jackshaft and its gearing.

In the direct drive proposed we at once run into the same difficulties that have been already experienced with the use of high-pressure steam in steam locomotives. That is, good expansion ratios from a very high pressure to a low pressure give a high ratio of peak to mean pressure. The mean pressure is effective in work performance, but the design of the machinery on the other hand is dependent entirely on the peak pressure.

This condition on limited-cut-off steam engines has already caused considerable difficulties in regard to space limitations and also a marked increase in the weight of the machinery, thus limiting the available boiler capacity when applied to our larger locomotives. To get a good expansion ratio and take advantage of the higher pressures, and also to reduce the ratio of peak to mean pressure in any one cylinder and thus reduce the weight of machinery, particularly on the limited-weight driving axles, the writer's company has recently developed a three-cylinder compound locomotive operating at 350 lb. steam pressure. This locomotive has developed 4500 i.hp. or 3700 drawbar hp. at the remarkable weight efficiency of 100 lb. per i.hp.

If we consider the preliminary proportioning of cylinders for the D-H locomotive under straight Diesel performance at maximum horsepower and corresponding speed, we find the ratio of peak to mean pressure excessive as compared with steam locomotives.

Further, since the ratio of starting to speed torque at maximum horsepower for satisfactory road performance should not exceed 2 to 2.3, we shall find that the same cylinders already proportioned for Diesel performance, when operating by steam in starting, will require very early cut-offs as compared with ordinary steam locomotives. It is therefore apparent that to meet the peak pressure for Diesel performance will require very large piston loads, necessitating large axles, heavy frames, and limited-size wheel centers.

In the performance of a locomotive a very severe requirement is that of developing large horsepowers at relatively low speeds, i.e., from 50 to 80 r.p.m. This condition brings a maximum demand on the boiler, because the engine efficiency is at its poorest, due to the meeting of maximum-torque requirements. With the proposed D-H locomotive, the Diesel power is either nil or, if in operation, relatively low due to the low r.p.m., so that the boiler capacity must be fairly large.

Therefore the practicability of this locomotive, aside from the cylinder performance, depends essentially upon whether the increased weight of machinery will permit sufficient boiler capacity to meet the above requirements, and at the same time meet the limited axle loadings and weights now demanded in large motive power.

In the jackshaft drive we encounter some very difinite limitations which would require a multiplicity of unit to meet the tractive-force requirements. It is known (see discussion by writer on the "Zoelly Turbine Locomotives," Trans. A.S.M.E., vol. 46, 1924), that 180,000 lb. adhesive weight is approximately the extreme limit for one jackshaft drive. To meet modern power tractive requirements would therefore require two jackshaft units. We have, of course, the same power demands and boiler requirements as before, but due to the higher speed of the engine and the fact that it is self-contained, a reduction in the weight of the engine may more than compensate for the two jackshafts. The cost, however, would probably be greater, due to the necessity of two separate units.

W. A. Pownell.[9] Although at present the average main-line steam locomotive has an overall thermal efficiency of 6 to 8 per cent, some of the more modern types of locomotives making use of all economy developments and devices have a somewhat higher efficiency. The steam-turbine locomotive, of which there are already a few in service, promises a thermal efficiency of around 16 per cent, and this probably represents nearly the maximum that may be expected from the steam locomotive for some time to come. The Diesel locomotive offers a thermal efficiency of about 33 per cent, or practically twice that of the best that may be expected of the steam locomotive. It is the writer's understanding that the author's Diesel steam locomotive will have a combined thermal efficiency which may average possibly 25 per cent, this average of course depending on the percentage of time that the locomotive is worked all-Diesel, all-steam, or steam-Diesel.

A. I. Lipetz in a paper read before the A.R.A. Mechanical Division at the 1927 meeting at Montreal stated that the Still engine used in marine service gave on tests thermal efficiencies of 37.1 and 36.4 per cent, respectively.

It seems to the writer that the comparison between the steam and Diesel-electric locomotives shown in Fig. 1 may not be exactly fair to the Diesel, since in this case the Diesel is probably of considerably lower horsepower than the steam locomotive with which it is compared, and the Diesel-electric tractive-power effort would therefore be considerably less than that of the steam locomotive as the speed increased.

The author's locomotive is based on the assumption that the

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[9] Mechanical Engineer, Wabash Railway Co., Decatur, Ill.

average demand on the present locomotive as it moves a train over the road is only 50 to 75 per cent of the maximum, depending on the service and nature of the road. This is true in general, although there may be some classes of service, such as time freight service or heavy freight trains that move over a low-grade line without much interference, where the average demand comes somewhat closer to the total available power of the locomotive. As a matter of information the writer submits the curve of Fig. 11 which shows the cylinder horsepower of a modern locomotive, developed over a 100-mile run in heavy freight service over a district having 0.4 per cent ruling grade. This curve was taken from actual dynamometer records, and the engine used had available boiler horsepower of 2760. In this case the average cylinder horsepower was about 75 per cent of the available horsepower.

Inasmuch as our modern practice of using superheated steam practically takes care of cylinder condensation, the writer does not see that the fact that the steam would expand in hot Diesel cylinders would be any additional advantage from this standpoint. However, on the other hand, if the hot Diesel cylinder will take care of cylinder condensation, it might be possible to do away with superheating the steam.

It is stated in the paper that steam and products of combustion

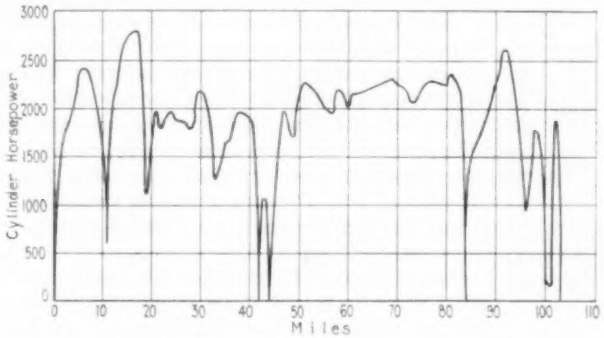


FIG. 11 CYLINDER HORSEPOWER DEVELOPED BY A MODERN LOCOMOTIVE OVER A 100-MILE RUN IN HEAVY FREIGHT SERVICE

of the Diesel can be mixed and do no harm to the cylinder liners and pistons. It may not be an analogous case, but most car drivers find that automobile engines seem to work better when there is a light rain or heavy fog, and there have been several devices on the market for injecting water into the manifold of the automobile engine. However, it is the writer's understanding that this practice has been discouraged on account of the expected dissolving effect of the mixture on the metal in the cylinders.

In the author's arrangement it is stated that the Diesel is to begin to operate when the speed of the locomotive reaches 4 m.p.h. With a 63-in.-driver locomotive, which is a very common size for modern freight engine, this would mean only $21^1/_3$ r.p.m., which seems rather low for Diesel-engine operation.

One incidental problem which is not mentioned in the paper is that of suitable draft for the fire of the steam boiler. Modern locomotives use induced draft produced by a jet of steam through the exhaust-nozzle tip, and which at the same time is responsible for more or less back pressure on the pistons of the engine. It would be rather impracticable to produce draft by this same method with a combined Diesel-steam locomotive, and the writer understands it would not be advisable to put this back pressure on the pistons. The alternative is the production of draft with an induced-draft fan, which, while it has been tried out to some extent in Europe and experimentally in this country, has not yet been successfully developed. This is of course an incidental problem, but one which will have to be given careful consideration.

If the initial cost of the D-H locomotive will, as stated in the author's answer to question 17, be approximately the same as that of a steam locomotive of equal capacity, it will overcome one of the principal objections that have been raised so far to the Diesel-electric locomotive, namely, its high initial cost.

If the D-H engine will give at least twice the thermal efficiency of the present steam locomotive, as seems probable, it will certainly result in a very large fuel saving, and one that will justify the interest and support of transportation men in the development of this steam-Diesel type of locomotive.

EDGAR J. KATES.[10] Although the author expects to use only Diesel power in the locomotive cylinders when pulling the train at normal speed and average load, it seems likely that in an engine as commercially built and practically used, steam will be admitted to the cylinders for a considerable portion of the running time.

In this case it becomes necessary to study fully the effect that the introduction of large amounts of steam will have on the Diesel cycle. The author mentions that there will result a heat exchange between the steam and the gases, that the hot gases will be cooled to a certain extent, and that the entering steam will be superheated. This, in the writer's opinion, might result in the hot gases being cooled something like 1000 deg. fahr., in which case it would seem that the Diesel efficiency would be seriously reduced because of the temperature degradation. A complete thermodynamic calculation on this point would be enlightening.

C. A. JACOBSON.[11] This paper, the writer believes, is the first one that has been discussed in this country on the direct-drive locomotive. He disagrees with the author that light-weight engines will not wear. If we take solid-injection engines of 50 lb. weight, they will be found to wear very much better than anything that is used in the steam locomotives which are at present in use on the railroads. Of course, this Diesel-steam process has not been tried so we are not sure that it will work out satisfactorily and undoubtedly there will be a great deal of development work required to perfect it.

The geared arrangement would be the most suitable as it would allow the most advantageous arrangement on the locomotive as far as weight distribution is concerned, with the separation of pressure and stress generated from the wheels from those generated by the engine, and it would also allow better ratios, so that a lighter engine could be built. Even on a direct-drive locomotive it would be unnecessary to add weight such as a boiler, as there would be more weight than was required. That would depend entirely upon the type of service in which the locomotive was placed. A passenger-steam locomotive may run down to 100 lb. per hp.

There is a decided disadvantage with the author's scheme, and very likely this will be true of the Kitson-Still locomotive. It will not be smokeless by any means. At the present time that is the chief reason for adopting a Diesel locomotive. Around New York City probably every such locomotive has been bought on that account. In other cases, of course, the reason has been branch-line operation. Smoke would even be very serious in main-line operation. Clean operation is probably one of the best reasons for the adoption of the locomotive, aside from its economy.

It may be of interest to note that the first gear-drive locomotive has been in regular operation since January 1, 1927.

[10] Consulting Engineer, New York, N. Y., Mem. A.S.M.E.

[11] American Crusher & Machinery Co., New York, N. Y.

One of the high officials of the German State Railways who recently returned from Russia has stated that there was no maintenance except what was required on the ordinary steam locomotive such as brakes. He stated that, in his opinion, the type was one of the best designed for main-line work, and it is expected that the German State Railways will place orders with the German licensees for a number of them. The Japanese State Railways have just placed an order for 15 of these locomotives, and very soon in this country there will be an opportunity to see one which was built by Krupp in Germany.

Mr. Lipetz said something about the efficiency of the mechanical gear-drive locomotive being as low as 12 to 13 per cent at times. That is true of any locomotive; when it is running on a partial load its efficiency is probably very low compared with its maximum. The electric drive would probably have a maximum transmission efficiency of 75 per cent at one load and speed, but at others it might be very poor. That has to be taken into account with any type of locomotive.

It seems to the writer that one of the chief things to get away from is the idea that a Diesel engine should only run at a mean effective pressure of 70 or 80 lb. We impose no such limit when we build a truck engine or an aviation engine, but build it so that it will give the highest horsepower output that can be possibly gotten out of it. The same thing should be true in a locomotive. A test was made in Europe with the four-cycle mechanical-injection type with the normal m.e.p. at 85 lb., and at that rate the fuel consumption was 0.37 lb. per hp. When the maximum mean effective pressure was 120 lb. the exhaust was just barely visible. The corresponding fuel consumption was 0.4 lb. for that increase of 50 per cent in the mean effective pressure and capacity of that engine, there was no difference as far as smoke was concerned, and the fuel economy was still very good. That increase in fuel consumption would be a very minor thing in locomotive operation where the periods of maximum power output would be comparatively small, and the majority of the time the power required would be very much less than the maximum.

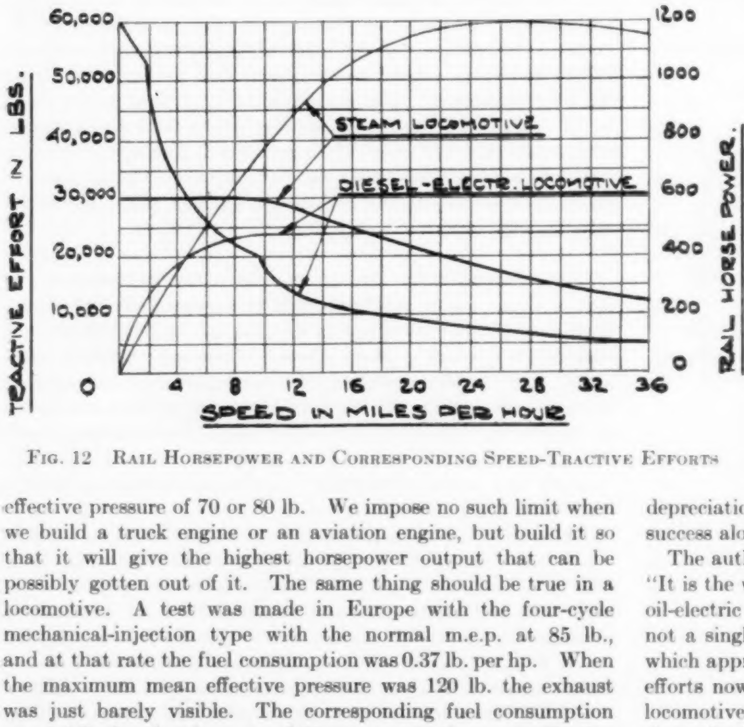


Fig. 12 Rail Horsepower and Corresponding Speed-Tractive Efforts

The Author. The whole discussion has not set forth a single argument which would make the proposed D-H locomotive questionable. A careful reader of the paper will find therein adequate replies to many of the remarks made during the discussion. Some of them are not sufficiently to the point to justify dealing with them. However, there are some which need a reply.

There is a fixed relation between rail horsepower and tractive effort at a given speed which is expressed by the following equation:

$$\text{Rail horsepower} = T \times 88S/33{,}000 = 0.00266\ TS$$

Here $T$ signifies the tractive effort in pounds, and $S$ the speed in miles per hour (one mile per hour equals 88 ft. per min.). The prime mover, whether it is a constant-torque or a constant-speed engine, must deliver the equivalent rail horsepower to obtain a given speed-tractive effort.

Fig. 12 shows the rail horsepower and the corresponding speed-tractive efforts. At the point where the curves of the latter intersect, both engines will develop the same horsepower. At lower speed the Diesel-electric, at higher speed the steam engine, develops the most horsepower and consequently the higher tractive effort.

Mr. Lemp states: "In reference to Fig. 1, it is evident that by changing the gear of the motor drive, the tractive effort (of the Diesel-electric locomotive) at the start may be lessened and higher speeds made possible." Generally speaking, when using a constant-speed engine, changing gears can only increase the speed at the expense of tractive effort. For the tractive efforts at the higher speeds in Fig. 1 to equal those of the steam locomotive it would require a larger Diesel developing not 480 but 1200 rail hp.

Right here is the difficulty. The present main-line locomotive of customary size (27-in. × 32-in. cylinders) develops at higher speeds about 2400 rail hp. and weighs, when loaded, about 160 tons or 133 lb. per rail hp. On the other hand, let us take the 600-b.hp. Ingersoll-Rand Diesel-electric locomotive: Its weight is 100 tons, or 330 lb. per b.hp., or 390 lb. per rail hp. These figures show what the designer of the Diesel-electric locomotive is up against. If he wishes to install 2400 or even 4000 rail hp. (equal to 2850 or 4750 b.hp.) to obtain the tractive effort which the present steam locomotives at higher speeds develop (without overstepping their weights), he is compelled to use Diesels about as light as those for airships. This, however, is not practical as their first cost and their inherent high wear and depreciation are prohibitive, because for railroads commercial success alone counts.

The author cannot at all agree with Mr. Lemp when he states, "It is the writer's (Mr. Lemp's) belief that the real field of the oil-electric locomotive will be heavy main-line service." So far not a single main-line locomotive exists anywhere on the globe which approaches the rail horsepower and corresponding tractive efforts now developed by the present heavier type of main-line locomotives at higher speeds. He cites an article in the *Railway Age* referring to a test on a Diesel-electric locomotive pulling four passenger coaches. What are four coaches with a handful of passengers compared to a heavy freight train several city blocks long moving at a fairly swift speed? Besides, M. B. Richardson pointed out in reference to Mr. Lemp's statement that "that test was made primarily for branch-line service and not for main-line service."

Mr. Lemp questions the reliability of a boiler carrying 500 lb. pressure. Here the author wishes to mention that the following locomotives are at present under course of construction which use much higher boiler pressures than he intends to:

Swiss Locomotive Works, Buchli type, boiler pressure 800 lb.; engine speed 1000 to 1200 r.p.m. geared down to a jackshaft.

The Swiss Locomotive & Machine Co. is testing at present a locomotive using 875 lb. boiler pressure.

Schwartz & Co.'s Berlin Works, 2500-hp. engine; boiler pressure, 1500 lb.

Referring to the remarks made by Mr. Lipetz: The author cannot agree when he claims that "it would be a mistake to consider the use of steam in a locomotive to treat it from the point of view of power instead of tractive effort." Power and speed-tractive effort stand in a fixed relation to each other, as the above equation shows. The engine builder is accustomed to speak of "horsepower;" the railroad man of "speed-tractive effort;" but both terms are interchangeable.

Mr. Lipetz errs when he says that a constant-torque locomotive must be designed to correspond to the minimum torque, for otherwise the engine will be considerably underloaded, and its economy reduced for small tractive efforts. Most of the power plants, those of Diese electric locomotives included, operate with low *average* load factors. Why does Mr. Lipetz's suggestion not extend to the Diesel-electric locomotive and have its engine designed for a low load factor? Of course the suggestion cannot be realized in practice in either case because the engine must be of sufficient size to meet the maximum load.

Mr. Lipetz believes that the maximum piston forces of the D-H locomotive will exceed those of the present steam locomotive. This will not be the case, as a careful investigation has shown. He assumes that the highest mean effective pressure obtainable in double-acting two-stroke-cycle engines is only 60 to 65 lb. per sq. in. This is not the case. The figures just mentioned refer to continuous load and represent a very conservative rating. The author is informed that mean effective pressures of 80 lb. per sq. in. have been reached without difficulty. Here it should be kept in mind that the term "tractive effort" refers to the maximum of what the engine can furnish. This being the case, much higher mean effective pressures, and consequently smaller power cylinders, can be used than Mr. Lipetz assumes.

Mr. Lipetz's statement that in a steam locomotive any tractive effort below the maximum renders the engine more economical, is not quite correct. A locomotive at a given speed has a most favorable cut-off; below this the economy drops off rapidly.

Mr. Lipetz's statement that in a Diesel locomotive the efficiency decreases with diminished tractive effort is correct with a locomotive driven by straight Diesel power. This, however, is not the case in the D-H locomotive. On the contrary, the economy increases until about half the maximum tractive effort is reached, which corresponds to about the normal load obtainable by straight Diesel power. Below this the efficiency remains first nearly constant (a characteristic of the Diesel cycle), and then begins to fall off more noticeably.

When Mr. Lipetz refers to the Still engine, pointing out that the piston top tends to superheat the steam, it should be mentioned that this is probably more than counterbalanced by the fact that the steam end of the cylinder has an extremely undesirable shape. That the steam consumption in the Still engine cannot be favorable may be judged from *Power*, vol. 64, page 730. Here a 2500-hp. marine Still engine is referred to, making use of the exhaust gases and the heat supplied to the water jackets. An economizer and a 27-in. vacuum are used, and yet only 14 per cent of the total power output is delivered by the steam unit. The D-H locomotive will have a much better steam consumption, and it will make use of the waste heat of the engine in a manner somewhat similar to that of the Still locomotive.

The author feels certain that Mr. Eksergian is not correct when he assumes that the weight of the D-H locomotive, shown in Fig. 7, will be materially higher than that of a steam engine of equal tractive effort. Here it should be considered that the boiler capacity needs to be only a fraction of that of the steam locomotive.

The author is fully aware that a direct-connected straight Diesel would give an undesirable ratio of peak to mean crankpin forces. This is one reason why he proposes the combination of Diesel and steam power and intends to proportion the cylinders for only 50 per cent straight Diesel. Mr. Eksergian says, "If we consider the preliminary proportioning of cylinders for the D-H locomotive under straight Diesel performance at a maximum horsepower and speed, we find..." The conclusions drawn on this assumption are not to the point in regard to the D-H locomotive.

Professor Schweitzer should be commended for his disinterested and unbiased remarks. He admits that, at average load, the D-H locomotive on account of its better load factor will consume about 10 per cent less fuel than a straight Diesel locomotive. The author would ask whether 10 per cent is not worth saving in addition to the considerable losses encountered by the generator and motors which alone amount to 15 to 35 per cent, depending on the load.

The author wishes to thank Mr. Pownell for furnishing a chart of an actual dynamometer record on a 100-mile run, having 0.4 per cent ruling grade, showing an average cylinder horsepower of about 75 per cent over the maximum.

It is true that superheating the steam in a steam locomotive reduces cylinder condensation, but it does not prevent it completely as does the D-H locomotive.

Mr. Pownell questions that the firing of the power cylinders will take place at a speed as low as four miles per hour. This depends on the heat at the end of the compression stroke. Using airless fuel injection and steam for starting eliminates the refrigeration effect which the use of air has in ordinary Diesels, making the D-H locomotive start much easier.

Referring to Mr. Jacobson's remark, it is a well-known fact that nearly all Diesels of medium and larger sizes are rated much below their maximum capacity. The reason is not that the Diesel could not be successfully operated at continuous higher loads, but that the average engineer under the average plant conditions will do very much better if his Diesel is not loaded to the utmost. The maintenance cost will be lower. Larger Diesels should not be compared with automobile and aviation engines because here the stresses are harder to deal with than in smaller cylinder sizes. This makes supercharging practical for smaller Diesels but questionable for larger ones.

In conclusion, the author would say that the D-H locomotive is a typical heavy-duty main-line engine. It does not deviate radically from customary practice as the straight Diesel locomotive does. Using a much smaller boiler but a greater number of cylinders, its weight and its crankpin forces will be within customary limits. Adding a fuel-injection pump and a scavenging-air blower will not materially affect its simplicity but will permit the introduction of the Diesel cycle and will completely eliminate all cylinder condensation. This will increase the efficiency over the steam locomotive a few hundred per cent, and will maintain its flexibility and its favorable tractive efforts at higher speeds.

The D-H locomotive will require some development work, but there is no question in the author's mind relative to its success, its revolutionizing effect on the railroads, and its importance relative to national economy. He expresses his hope that he will succeed in obtaining financial assistance which will enable him to prove by actual demonstration the value of the D-H locomotive.

# Efficiencies of Otto and Diesel Engines[1]

By F. O. ELLENWOOD,[2] ITHACA, N. Y., F. C. EVANS,[3] NEWPORT, DEL., AND C. T. CHWANG,[4] WASHINGTON, D. C.

*This paper gives primarily the results of calculations for the ideal Otto and Diesel engines in which the working substance is a mixture of real gases. The results are presented in the form of convenient tables and curves that may be readily used by any engineer in the determination of the engine efficiencies of internal-combustion motors operating under the various conditions existing today. The general method of procedure is fully explained and the necessary equations are given.*

*The paper also considers the factors involved in the establishment of "real-mixture standards" on which to base the performance of Otto and Diesel engines, and compares the results obtained by somewhat different conceptions. The use of higher and lower heating values of the fuel in the various calculations involved is discussed, and the tables and curves for the 65 cases considered give the results for both values.*

*The importance of using engine efficiencies to express performance is stressed, and five illustrative examples indicate that some of the best internal-combustion motors have already been so well designed and built that they give the excellent result of engine efficiencies as high as 76 per cent.*

FOR SOME years engineers have realized the importance of knowing the laws governing the variable specific heats of gases at high temperatures in order that they may make more satisfactory calculations of the ideal cycles of internal-combustion motors than was possible by the so-called "air standard" method formerly in use. The experimental data relating to these specific heats are not all in close agreement, but Goodenough and Felbeck[5] have recently assembled this information and presented equations that the authors accept as representing the most reliable values available to date. If engineers agree on the specific heats of gases, the chief uncertainty regarding the solution of problems based on the ideal Otto and Diesel cycles has been removed. However, there still remain certain points about which there may be differences of opinion.

This paper, therefore, has the following objects:

1 To discuss the factors involved in the determination of the ideal Otto and Diesel cycle efficiencies that may be used as logical standards;

2 To give the results of calculations for the ideal engines using various compression ratios and fuel mixtures, when considering the variable specific heats, but not dissociation; and to show the significance of these results in expressing the performance of internal-combustion engines;

3 To compare these results with those in which dissociation has been considered;

4 To present a few fairly typical illustrations of the efficiencies of modern engines.

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[4] Formerly graduate student of Heat-Power Engineering, Cornell University. Jun. A.S.M.E.

[5] Bulletin No. 139, University of Illinois, 1924.

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### Ideal Otto and Diesel Cycles Defined

The ideal Otto engine herein considered is one in which the cycle is completed under the following conditions:

(*a*) There is no transfer of heat to or from the mixture while in the cylinder.

(*b*) There is no leakage, fluid friction, or mechanical friction in this engine.

(*c*) The mixture at the beginning of compression is assumed to be a gas having atmospheric pressure and a temperature of 200 deg. fahr.

(*d*) The compression and expansion ratio $r$ is equal to $(100 + c)/c$, where $c$ represents the clearance of the engine in per cent of piston displacement. The value of $c$ is to be chosen the same as it is in the actual engine with which the ideal is being compared.

(*e*) The mixture in the cylinder during compression is composed of air, fuel, and residual gases. The air-fuel ratio is chosen for the ideal engine to be the same as that obtained by test of the actual engine with which comparison is to be made, *provided the actual engine has at least sufficient air to permit complete combustion of the fuel. If the actual engine is operated with a deficiency of air, the air-fuel ratio in the ideal engine is then taken as just sufficient to afford complete combustion of all of the fuel.* The weight of residual gases cannot be calculated accurately, but it is assumed to be sufficient to fill one-half of the clearance volume when reduced to the pressure and temperature previously assumed at the beginning of compression.

(*f*) No dissociation is considered; in other words, all combustion is assumed to take place at constant volume, and the corresponding rise in the temperature of the products of combustion is just sufficient to account for the lower heating value of the known weight of fuel used per cycle.

For the ideal Diesel engine, conditions (*a*), (*b*), and (*c*) are assumed to hold as given for the Otto, while (*d*) is modified by having the expansion ratio less than the compression ratio due to the injection of fuel at constant pressure during part of the stroke, (*e*) is changed by eliminating the fuel from the mixture during compression, and (*f*) assumes that combustion occurs at constant pressure as the liquid fuel is injected.

The reason for considering the ideal engine to have at all times at least sufficient air to burn completely all of the fuel used is that, in the opinion of the authors, only by such a procedure can the heating value of the fuel be fairly used as a base on which the efficiency is measured. The mere fact that in certain types of Otto engines it may be desirable, for purely commercial or personal reasons, to operate an engine without sufficient air to burn the fuel, does not necessarily méan that the ideal engine is one through which part of the fuel is considered to pass without any possibility of complete combustion. The modern automobile engine is often operated with a deficiency of air in order to give a more flexible motor and at the same time yield its maximum power per unit of piston displacement. Fundamentally, however, this engine is still a heat engine, and it seems to the authors that in calculating the energy available from each unit of fuel it should be assumed that all of the fuel is to be completely burned, as is done with all other ideal heat engines. If any engine fails to burn its fuel completely, it certainly seems reasonable to expect its engine efficiency to be reduced thereby, and that is exactly what happens when the ideal is always considered to have at least sufficient air for complete combustion.

After establishing the conception of an ideal engine in which there is never a deficiency of air, the question of dissociation is next in order. The effect of dissociation on the efficiencies of the ideal cycles involving no deficiency of air is small, and it is therefore questionable whether such a refinement is warranted in the calculation of such ideal cycles, because of the following uncertainties involved:

*a* The amount of dissociation occurring within the cylinder of the real engine and the proper laws to use in considering dissociation in the corresponding ideal engine;

*b* The specific heats of the mixture in the cylinder at various temperatures;

*c* The composition and temperature of the mixture (including dilution) in the cylinder at the beginning of compression in the actual engine; and

*d* The composition and heating value of the fuel used.

Dissociation usually does not affect the efficiency of the ideal Diesel engine to as great an extent as it does that of the Otto engine, because dissociation is decreased by low temperature and the Diesel engine is commonly operated with a large percentage of excess air so that the maximum temperatures involved are less than in the Otto engine.

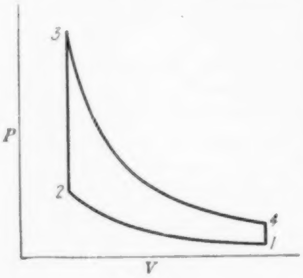


FIG. 1

## EQUATIONS USED

Since the ideal cycles are to be calculated for a mixture of gases whose composition varies with the compression ratio, fuel used, and air-fuel ratio, it is necessary to determine the equations for the specific heats of each mixture before and after combustion. The specific heats of a mixture of gases can be represented in terms of the absolute temperature $T$ by the equations

$$c_v = M + BT + CT^2$$

and

$$c_p = M' + BT + CT^2$$

where $M'$, $M$, $B$, and $C$ are constants for each gas mixture. As an illustration, consider the mixture of three gases with the respective weights $w_1$, $w_2$, and $w_3$, the same subscripts also being used to indicate the constants of each constituent. Then for this mixture

$$M = \frac{w_1M_1 + w_2M_2 + w_3M_3}{w_1 + w_2 + w_3} \ldots\ldots\ldots\ldots\ldots [1]$$

$$B = \frac{w_1B_1 + w_2B_2 + w_3B_3}{w_1 + w_2 + w_3} \ldots\ldots\ldots\ldots\ldots [2]$$

$$C = \frac{w_1C_1 + w_2C_2 + w_3C_3}{w_1 + w_2 + w_3} \ldots\ldots\ldots\ldots\ldots [3]$$

$$M' = \frac{w_1M'_1 + w_2M'_2 + w_3M'_3}{w_1 + w_2 + w_3} \ldots\ldots\ldots\ldots\ldots [4]$$

Also for $w$ pounds of this mixture having an absolute pressure of $p$ lb. per sq. in. and a volume of $V$ cu. ft., the constant $R$ is such that

$$\frac{144pV}{wT} = R = 778\,(c_p - c_v) = 778\,(M' - M) \ldots\ldots [5]$$

The mixture in the Otto- and Diesel-engine cylinders always contains some residual gases during compression. Therefore both the fuel mixture and the products mixture will contain a certain amount of $CO_2$, which means, according to Goodenough and Felbeck, that the gas constants will be different above and below 2900 deg. fahr. abs. Let the subscript zero be attached to the gas constants to be used with values of $T$ less than 2900. The actual values of the constants for the constituent gases, as used in the calculations, are given in Table 1. By the aid of the values given in this table and Equations [1] to [5], inclusive, the constants for the mixtures involved in each case were calculated and the results are clearly shown in the other tables.

TABLE 1 GAS CONSTANTS FOR CONSTITUENTS OF MIXTURES

| | $M'$ | $M$ | $B(10)^6$ | $C(10)^9$ | $R$ |
|---|---|---|---|---|---|
| $C_6H_6$ (Benzene) | 0.0513 | 0.0258 | 40.77 | 0 | 19.80 |
| $C_7H_8$ (Toluene) | 0.0435 | 0.0219 | 34.60 | 0 | 16.80 |
| $C_8H_{10}$ (Xylene) | 0.0377 | 0.0190 | 30.00 | 0 | 14.55 |
| $C_8H_{18}$ (Gasoline) | 0.3358 | 0.3184 | 33.29 | 0 | 13.53 |
| $O_2$ | 0.2166 | 0.1545 | 0 | 3.750 | 48.26 |
| $N_2$ | 0.2474 | 0.1765 | 0 | 4.283 | 55.12 |
| $H_2$ | 2.9762 | 1.9916 | 33.07 | 0 | 766.03 |
| $H_2O$ | 0.4624 | 0.3522 | −1.532 | 23.48 | 85.72 |
| CO | 0.2474 | 0.1765 | 0 | 4.283 | 55.12 |
| $CO_2$, $T < 2900$ | 0.1625 | 0.1174 | 8.864 | −13.64 | 35.10 |
| $CO_2$, $T > 2900$ | 0.2772 | 0.2321 | 0.9545 | 0 | 35.10 |

As soon as the specific-heat equations are known, it is then possible to calculate the values of internal energy and enthalpy (or heat content) of any mixture having a known temperature, or vice versa. Equations [6] to [13], inclusive, which follow, are used for this purpose.

Specific Heat at Constant Volume, $c_v$

$$\text{If } T < 2900, \quad c_v = M_0 + B_0T + C_0T^2 \ldots\ldots\ldots [6]$$

$$\text{If } T > 2900, \quad c_v = M + BT + CT^2 \ldots\ldots\ldots [7]$$

Specific Heat at Constant Pressure, $c_p$

$$\text{If } T < 2900, \quad c_p = M'_0 + B_0T + C_0T^2 \ldots\ldots\ldots [8]$$

$$\text{If } T > 2900, \quad c_p = M' + BT + CT^2 \ldots\ldots\ldots [9]$$

Specific Internal Energy, $i$

$$\text{If } T < 2900, \quad i = \int_0^T c_v dT = M_0T + \frac{B_0T^2}{2} + \frac{C_0T^3}{3} \ldots\ldots [10]$$

$$\text{If } T > 2900, \quad i = i_{2900} + \int_{2900}^T c_v dT$$

$$= (M_0 - M)2900 + \frac{B_0 - B}{2}\,(2900)^2 + \frac{C_0 - C}{3}\,(2900)^3 + MT + \frac{BT^2}{2} + \frac{CT^3}{3} \ldots [11]$$

Specific Enthalpy (or heat content), $h$

$$\text{If } T < 2900, \quad h = \int_0^T c_p dT = M'_0T + \frac{B_0T^2}{2} + \frac{C_0T^3}{3} \ldots\ldots [12]$$

$$\text{If } T > 2900, \quad h = h_{2900} + \int_{2900}^T c_p dT$$

$$= (M'_0 - M')\,2900 + \frac{B_0 - B}{2}\,(2900)^2 + \frac{C_0 - C}{3}\,(2900)^3 + M'T + \frac{BT^2}{2} + \frac{CT^3}{3} \ldots [13]$$

First consider the ideal Otto engine, for which the lines 1–2 and 3–4 of Fig. 1 represent on the pressure-volume diagram the isentropic compression and expansion curves, respectively, of a definite weight of working substance. It is not necessary to consider the suction and exhaust strokes for the ideal engine because it is assumed that there is no fluid friction, and consequently the area of the diagram would not be affected by them. The line 2–3 represents the rise in pressure of the products mixture due to

combustion, which is considered as taking place at constant volume and without any transfer of heat to or from the working substance. The line 4–1 represents the extremely rapid drop in pressure of the products mixture remaining in the cylinder while the piston is at the end of the stroke after the exhaust valve opens at 4 and lets most of the gases rush out to the atmosphere. This exit of exhaust gases does no work on the piston, and the effect of it on this diagram is the same as though all of the gases had been cooled at constant volume from 4 to 1.

The relation between temperature and volume of a mixture, having variable specific heats, when undergoing an isentropic compression or expansion is now required. The temperature $T_1$, the ratio of compression, $r = V_1/V_2$, and $w$ pounds of a certain mixture are assumed for the case under consideration.

TABLE 2 GAS CONSTANTS FOR EXPANSION MIXTURE IN OTTO ENGINE

| Fuel | | Lb. air per lb. fuel | Per cent air | $M$ ($T > 2900$) | $M_0$ ($T < 2900$) | $B(10)^5$ ($T > 2900$) | $B_0(10)^5$ ($T < 2900$) | $C(10)^9$ ($T > 2900$) | $C_0(10)^9$ ($T < 2900$) | $R$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Gasoline $C_8H_{18}$ | | 15.2 | 100 | 0.2026 | 0.1808 | 0.0485 | 1.556 | 5.150 | 2.550 | 54.10 |
| | | 16.7 | 110 | 0.2000 | 0.1799 | 0.0440 | 1.427 | 5.060 | 2.674 | 54.06 |
| | | 18.2 | 120 | 0.1980 | 0.1792 | 0.0403 | 1.312 | 5.002 | 2.852 | 54.05 |
| | | 20.5 | 135 | 0.1950 | 0.1785 | 0.0357 | 1.173 | 4.910 | 2.950 | 53.99 |
| | | 22.8 | 150 | 0.1927 | 0.1778 | 0.0320 | 1.058 | 4.838 | 3.069 | 53.97 |
| "90%" Benzol | $C_6H_6$ 73% | 13.48 | 100 | 0.1985 | 0.1717 | 0.1470 | 1.994 | 4.195 | 1.015 | 52.09 |
| | $C_7H_8$ 23% | 16.18 | 120 | 0.1943 | 0.1717 | 0.1240 | 1.680 | 4.226 | 1.558 | 52.32 |
| | $C_8H_{10}$ 4% | 20.22 | 150 | 0.1901 | 0.1719 | 0.1002 | 1.358 | 4.220 | 2.060 | 52.69 |
| Blast-furnace gas | CO (Vol.) 28% | 0.744 | 100 | 0.1971 | 0.1590 | 0.2975 | 2.934 | 3.064 | −1.486 | 48.82 |
| | $H_2$ (Vol.) 3% | 0.893 | 120 | 0.1952 | 0.1600 | 0.2690 | 2.710 | 3.151 | −1.030 | 49.32 |
| | $CO_2$ (Vol.) 10% | 1.042 | 140 | 0.1935 | 0.1608 | 0.2584 | 2.516 | 3.223 | −0.657 | 49.63 |
| | $N_2$ (Vol.) 59% | .... | .... | .... | .... | .... | .... | .... | .... | .... |

Then with $I$ representing the internal energy, $Q$ the quantity of heat added during a process, and $A = 1/778$, it follows from the common energy equation that $dQ = dI + APdV$.

But from the relation $PV = wRT$, and remembering that $dQ = 0$ for an isentropic process, it must be true that

$$0 = dI + A\frac{wRTdV}{V}$$

But for $T < 2900$, $dI = wc_vdT = w[M_0 + B_0T + C_0T^2]dT$

$$\text{Hence} \qquad \left[\frac{M_0}{T} + B_0 + C_0T\right]dT = -A\frac{RdV}{V}$$

Then integrating between the limits $T_1$, $V_1$ and $T_2$, $V_2$ yields the following equation between $T$ and $V$:

$$M_0 \log_e \frac{T_2}{T_1} + B_0(T_2 - T_1) + \frac{C_0}{2}(T_2^2 - T_1^2)$$

$$= -AR\log_e\frac{V_2}{V_1} = AR\log_e\frac{V_1}{V_2} \qquad [14]$$

Let $K = 2.3026 = \dfrac{\log_e N}{\log_{10} N}$.

$$\text{Then } KM_0 \log\frac{T_2}{T_1} + B_0(T_2 - T_1) + \frac{C_0}{2}(T_2^2 - T_1^2) = KAR\log r$$

or

$$\log\frac{T_2}{T_1} + \frac{B_0}{KM_0}(T_2 - T_1) + \frac{C_0}{2KM_0}(T_2^2 - T_1^2) = \frac{AR}{M_0}\log r \qquad [15]$$

With the constants $M_0$, $B_0$, and $C_0$ for the fuel mixtures obtained from the tables of calculated results given later, the temperature at the end of compression $T_2$ is now found by means of Equation [15] for each case having $T_1$ and $r$ known.

After obtaining $T_2$ for the fuel mixture, the value of the specific internal energy $i_2$ at the end of compression is next obtained by means of Equation [10]. Then the work done by a unit weight of this mixture during compression is

$$\text{Work}_{1,2} = i_1 - i_2 \qquad [16]$$

From this equation, which will always yield a negative value since $i_2$ is greater than $i_1$, it is apparent that it is not the absolute value of the internal energy that is involved but only the difference of two internal energies, both of which must be measured above the same zero value, which is arbitrarily chosen.

For the rest of the cycle the problem deals with the products mixture. Here it should be noted that the internal energy of a fuel mixture at a given temperature and volume is not necessarily the same as the internal energy of the products mixture at the same temperature and volume. Consequently the next step in the solution is to find the internal energy of the products mixture $i'_2$ at the temperature $T_2$. This is done by using Equation [10] with the proper constants for the products mixture. The values of $i_2$ and $i'_2$ are given in the table for each set of calculations. Then by adding to $i'_2$ the energy evolved by the combustion of $w_f$ pounds of fuel per pound of mixture, the internal energy of the pound of mixture at the end of combustion is found. When the heating value of a fuel is determined experimentally, it is done by measuring the amount of heat abstracted from the products of combustion and not from the original mixture. Consequently

$$i_3 = i'_2 + w_f(\text{L.H.V.}) \qquad [17]$$

The lower heating value of the fuel should be used for this purpose because the temperatures at 2 and 3 are both far above the saturation temperature corresponding to the partial pressure of the water vapor formed by the combustion of any hydrogen in the fuel.

For the isentropic expansion the equation used is similar to that just developed for the compression curve, but it is complicated by the fact that in general two sets of gas constants are involved because the extremes of temperature usually lie both above and below 2900 deg. Assuming this condition to hold, the equation giving the temperature-volume relation for the expansion line 3–4 may be derived thus:

Let $T_d(=2900)$ and $V_d$ represent respectively the absolute temperature and volume of the products mixture at the dividing point $d$ between the equations of the two portions of the expansion line. Then above 2900,

$$M\log\frac{T_3}{T_d} + \frac{B}{K}(T_3 - T_d) + \frac{C}{2K}(T_3^2 - T_d^2)$$

$$= AR\log\frac{V_d}{V_3} \qquad [18]$$

and below 2900,

$$M_0\log\frac{T_d}{T_4} + \frac{B_0}{K}(T_d - T_4) + \frac{C_0}{2K}(T_d^2 - T_4^2)$$

$$= AR\log\frac{V_4}{V_d} \qquad [19]$$

Now, by adding Equations [18] and [19], there is obtained

$$\left[(M_0 - M)\log T_d + \left(\frac{B_0 - B}{K}\right)T_d + \left(\frac{C_0 - C}{2K}\right)T_d^2\right]$$

$$+ M\log T_3 - M_0 \log T_4 + \frac{BT_3 - B_0T_4}{K} + \frac{CT_3^2 - C_0T_4^2}{2K}$$

$$= AR\log\frac{V_4}{V_3} \qquad [20]$$

For any given mixture, the portion of Equation [20] that is enclosed by the brackets becomes a constant (since $T_d = 2900$) and consequently the solution of this equation to find $T_4$ is somewhat shorter than might be expected. However, in all of these equations of isentropic processes the solution involves the use of trial values of the unknown temperature until the equation is satisfied for the given ratio of expansion or compression.

After obtaining $i_3$, the value of $T_3$ is found by means of Equation [10] or [11]. Usually $T_3$ is above 2900 and consequently Equation [11] is used. Then by knowing the expansion ratio, $V_4/V_3$, the temperature $T_4$ is found by using Equation [20]. Next, the internal energy per pound of product mixture $i_4$ is obtained for the temperature $T_4$, and the work done by this mixture during its isentropic expansion is

$$\text{Work}_{3,4} = i_3 - i_4 \qquad [21]$$

Since the ideal cycle involves no fluid or mechanical friction the net work done by each pound of mixture in the ideal Otto engine is therefore

$$\text{Work}_i = i_3 - i_4 + (i_1 - i_2) \qquad [22]$$

The efficiency of this ideal engine is

$$e_i = \frac{\text{Work}_i}{w_f \times (\text{heating value of the fuel})} \qquad [23]$$

In this expression $w_f$ represents the weight of fuel used per pound of mixture.

The question of whether the higher or lower heating value should be used for this efficiency is debatable to the same extent as it is when determining the thermal efficiency of the actual engine. Since there is such a difference of opinion on this point among the engineers of the world, the efficiencies have been calculated for both the higher and lower values and the results are clearly indicated in the tables and curves. However, it should probably be stated again at this point that in Equation [17] the lower heating value should be used regardless of what value is used in Equation [23], because there is no possibility that the higher heating value is available to increase the temperature of the products of combustion above the temperature at the end of compression.

For the ideal Diesel engine the solution is carried out in a somewhat similar manner to that just outlined for the Otto. However, there are certain modifications that need to be observed on account of the fact that a definite weight of liquid fuel is injected after compression and is assumed to burn at constant pressure instead of constant volume. It should perhaps be emphasized here that in the actual engine it is only necessary to atomize the fuel finely (not vaporize) and mix it thoroughly with the air before it will ignite or burn readily. Tests show this to be true, and to assume that the fuel must be vaporized before injection in the ideal Diesel seems to the authors to be basically wrong and unnecessary.

Let Fig. 2 represent the $P$-$V$ diagram of this ideal engine. After assuming $T_1$, and finding the gas constants for the compression mixture (consisting of air and residual gases only), the values of $T_2$, $i_1$, and $i_2$ may be determined for the given compression ratio, as previously explained for the Otto. The work done by $w_c$ pounds of this compression mixture is found from the equation

$$\text{Work}_{1,2} = I_1 - I_2 = w_c(i_1 - i_2) \qquad [24]$$

The work done on the liquid fuel in pumping it into the cylinder of the actual Diesel engine is a very small fraction of the work done in compressing the air required for its combustion, and in the ideal Diesel the work done on the liquid fuel is still less because it is assumed there is no fluid or mechanical friction. As a matter of fact, for the ideal engine the work done on the liquid fuel is so small that it affects the net work of the cycle less

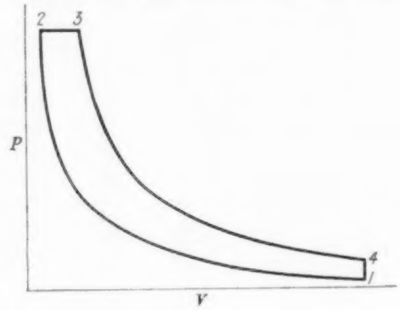


Fig. 2

than one part in 4000, and is therefore properly considered a negligible quantity in these calculations.

For the case of air injection of the fuel, it is not necessary to make any special calculations for the work of compression of the air in the corresponding ideal engine. This is because the work of compression in the ideal engine includes that required for the injection air if the correct air-fuel ratio is used. It is true that the actual engine must employ injection-air pressures much higher than the compression pressure, but this is due chiefly to fluid friction and the necessity of rapid injection, and consequently whatever loss is incurred by this extra pressure must appear in the reduced engine efficiency.

While $w_f$ pounds of the fuel are injected into the cylinder and burned at constant pressure, the work done by the resulting $(w_f + w_c)$ pounds of product mixture is

$$\text{Work}_{2,3} = AP_3V_3 - AP_2V_2 = (w_f + w_c)AP_3\overline{V}_3 - w_cAP_2\overline{V}_2 \qquad [25]$$

where $\overline{V}$ indicates specific volume.

During the isentropic expansion of the products mixture from 3 to 4, the work done is

$$\text{Work}_{3,4} = I_3 - I_4$$

$$= (w_r + w_c)(i_3 - i_4) \qquad [26]$$

By combining Equations [24], [25], and [26] and remembering that for any mixture the specific enthalpy is defined by the equation, $h = i + AP\overline{V}$, it follows that the net work for $(w_f + w_c)$ pounds of product mixture is

$$(w_f + w_c)(i_3 - i_4) + (w_f + w_c)AP_3\overline{V}_3 - w_cAP_3\overline{V}_3 + w_c(i_1 - i_2)$$

$$= (w_f + w_c)(h_3 - i_4) - w_c(i_1 - h_2)$$

Hence the net work in B.t.u. per pound of product mixture becomes

$$\text{Work}_i = (h_3 - i_4) - \left(\frac{w_c}{w_f + w_c}\right)(i_1 - h_2) \qquad [27]$$

Therefore the efficiency of the ideal Diesel engine is

$$e_i = \frac{(h_3 - i_4) - \left(\dfrac{w_e}{w_f + w_e}\right)(i_1 - h_2)}{w_f \times (\text{heating value in B.t.u. per lb.})} \quad \ldots\ldots [28]$$

In order to calculate the values needed in Equation [28], there are several points to be noted. As soon as the temperature at 2 is obtained the specific enthalpy $h_2$ of the compression mixture may be found by using Equation [12]; then, by the same equation but with different constants, it is necessary to find $h_2'$

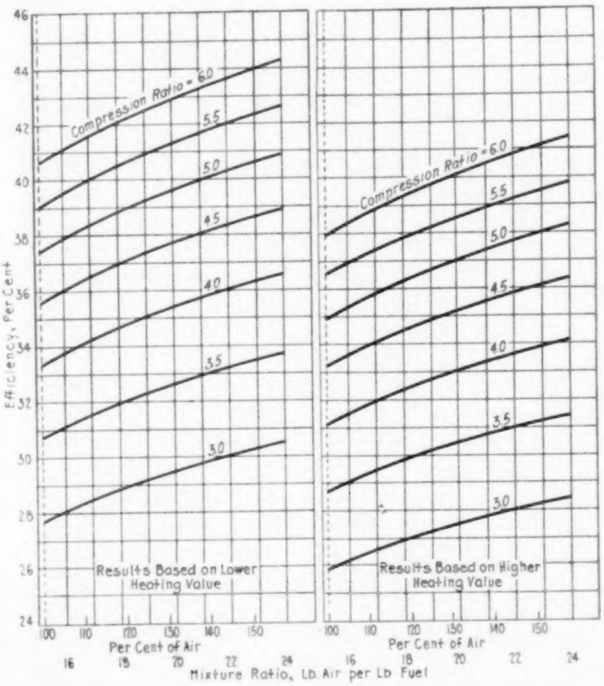


Fig. 3 Efficiency of Ideal Otto Engine Using Gasoline

the specific enthalpy of the product mixture at this same temperature, $T_2$. The calculation of $h_2'$ is essential because the experimental determination of the heating value of a fuel at constant pressure simply shows the amount of heat abstracted from the products mixture in order to cool it to its original temperature, the pressure being constant. Hence, if the lower heating value (L.H.V.) of the fuel is known, it follows that

$$h_3 = h_2' + w_f(\text{L.H.V.}) \quad \ldots\ldots [29]$$

From Table 8 it may be noted that $h_2'$ is appreciably different from $h_2$. After $h_3$ is found the corresponding temperature $T_3$ is obtained by using Equation [13].

Before $T_4$ can be found the ratio of expansion $V_4/V_3$ must be obtained. Since the pressure of $w_2$ pounds of the compression mixture at 2 is the same as $w_3$ pounds of the product mixture at 3, it follows that

$$V_3 = \left(\frac{w_3R_3T_3}{w_2R_2T_2}\right) V_2 \quad \ldots\ldots [30]$$

But $V_4 = V_1 = rV_2$, where $r$ represents the compression ratio. Therefore

$$\frac{V_4}{V_3} = \left(\frac{w_2R_2T_2}{w_3R_3T_3}\right) r \quad \ldots\ldots [31]$$

Then by using Equations [20] and [31], $T_4$ is obtained and consequently $i_4$ may be found from Equation [10] if $T_4$ is less than 2900 deg. and from Equation [11] if $T_4$ is greater than that value.

## Results of Calculations and Their Significance

By using the method just outlined for the Otto and Diesel cycles, the results, as shown in Tables 3, 4, and 5, were obtained. Special effort has been made to make clear the meaning of each column by means of suitable names as well as by the symbols used in the formulas. The term "100 per cent air" means that amount necessary to supply just sufficient oxygen to burn the fuel completely, and "120 per cent air" means 20 per cent more than is necessary for this purpose.

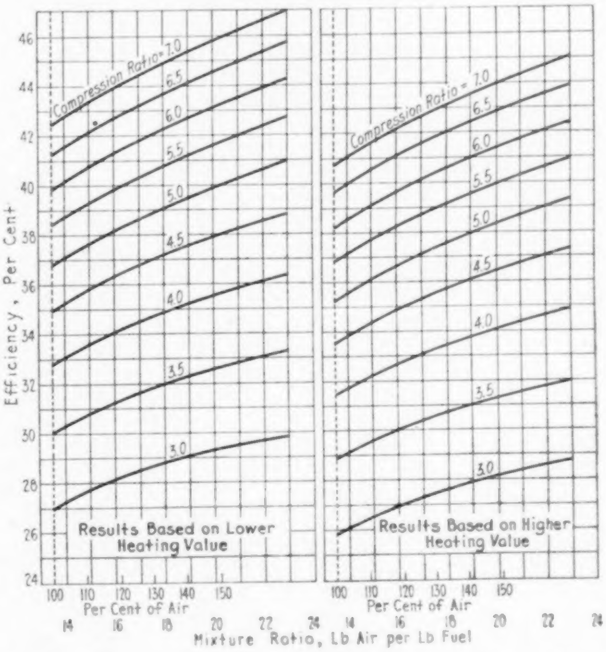


Fig. 4 Efficiency of Ideal Otto Engine Using "90 Per Cent" Benzol

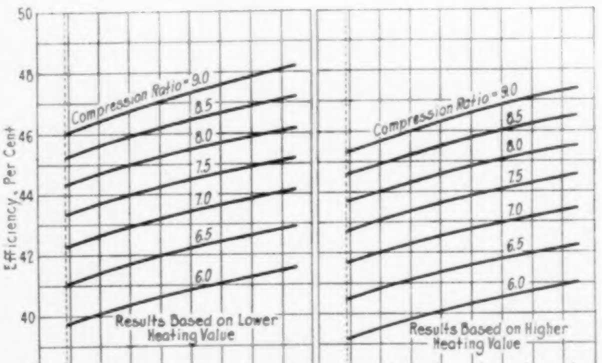


Fig. 5 Efficiency of Ideal Otto Engine Using Blast-Furnace Gas

For the Otto engine, using gasoline, 90 per cent benzol, and blast-furnace gas, the results are also given in Figs. 3, 4, and 5, respectively. The efficiencies were plotted against the mixture ratio, because this set of axes gives the best distribution of the curves in a given space.

The curves for each of the three fuels are similar and are only displaced from each other by a maximum difference of slightly more than 2 per cent for any given compression ratio and the

TABLE 3 CALCULATED RESULTS FOR IDEAL OTTO ENGINE WITH GASOLINE[1] AS FUEL

| Case number | Compression ratio $r$ | Lb. air per lb. fuel | Per cent air | Lb. residual gas per lb. fuel | Gas constants for fuel mixture: $M$ | $B(10)^4$ | $C(10)^9$ | $R$ | Gas constants for products mixture | Abs. temperatures, deg. fahr.: Beginning of compression $T_1$ | End of compression $T_2$ | Beginning of expansion $T_3$ | End of expansion $T_4$ | Internal energies, B.t.u. per lb. mixture: Fuel mixture: Beginning of compression $i_1$ | End of compression $i_2$ | Products mixture: End of compression $i_2'$ | Beginning of expansion $i_3$ | End of expansion $i_4$ | Net work, B.t.u. per lb. mixture $\text{Work}_i$ | Heat supplied, B.t.u. per lb. mixture, based on lower h. v. $Q_i$ | Efficiencies, per cent: Based on lower h. v. $e_i$ | Based on higher h. v. $e_i'$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 15.2 | 100 | 4.05 | 0.1805 | 0.1949 | 3.636 | 51.78 | See Table 2 | 660 | 954 | 4686 | 3609 | 123.6 | 181.9 | 180.2 | 1110.2 | 794.0 | 257.8 | 930 | 27.72 | 25.91 |
| 2 | 3 | 16.7 | 110 | 4.40 | 0.1799 | 0.1787 | 3.673 | 51.86 | | 660 | 957 | 4478 | 3409 | 122.7 | 181.9 | 179.9 | 1031.9 | 731.6 | 241.2 | 852 | 28.31 | 26.50 |
| 3 | 3 | 18.2 | 120 | 4.70 | 0.1794 | 0.1653 | 3.707 | 51.81 | | 660 | 961 | 4290 | 3233 | 122.5 | 180.7 | 179.3 | 967.3 | 681.0 | 228.0 | 788 | 28.93 | 27.08 |
| 4 | 3 | 20.5 | 135 | 5.25 | 0.1784 | 0.1477 | 3.761 | 52.29 | | 660 | 969 | 4044 | 3005 | 121.5 | 181.1 | 179.4 | 883.4 | 616.2 | 207.6 | 704 | 29.49 | 27.61 |
| 5 | 3 | 22.8 | 150 | 5.85 | 0.1787 | 0.1333 | 3.797 | 52.39 | | 660 | 970.5 | 3818 | 2802 | 121.3 | 180.6 | 178.4 | 813.4 | 562.3 | 191.8 | 635 | 30.20 | 28.24 |
| 6 | 4 | 15.2 | 100 | 2.67 | 0.1806 | 0.1986 | 3.713 | 51.65 | | 660 | 1047 | 4951 | 3581 | 123.8 | 201.0 | 198.5 | 1196.5 | 786.5 | 332.7 | 998 | 33.33 | 31.09 |
| 7 | 4 | 16.7 | 110 | 3.15 | 0.1797 | 0.1797 | 3.757 | 51.89 | | 660 | 1053 | 4705 | 3347 | 122.6 | 200.7 | 198.8 | 1101.8 | 715.5 | 308.2 | 903 | 34.13 | 31.94 |
| 8 | 4 | 18.2 | 120 | 3.22 | 0.1795 | 0.1672 | 3.786 | 52.02 | | 660 | 1055 | 4527 | 3182 | 122.5 | 200.0 | 197.6 | 1037.6 | 668.2 | 292.0 | 840 | 34.76 | 32.44 |
| 9 | 4 | 20.5 | 135 | 3.47 | 0.1794 | 0.1497 | 3.819 | 52.15 | | 660 | 1063 | 4285 | 2960 | 121.9 | 201.0 | 197.8 | 951.8 | 605.3 | 267.4 | 754 | 35.47 | 33.18 |
| 10 | 4 | 22.8 | 150 | 4.03 | 0.1774 | 0.1322 | 3.852 | 52.30 | | 660 | 1071 | 4045 | 2749 | 120.3 | 199.1 | 198.5 | 874.5 | 550.1 | 245.5 | 676 | 36.32 | 33.94 |
| 11 | 5 | 15.2 | 100 | 1.96 | 0.1806 | 0.2003 | 3.756 | 51.57 | | 660 | 1124 | 5116 | 3521 | 123.8 | 217.5 | 214.6 | 1251.6 | 770.3 | 387.6 | 1037 | 37.38 | 34.92 |
| 12 | 5 | 16.7 | 110 | 2.18 | 0.1799 | 0.1828 | 3.782 | 51.82 | | 660 | 1133 | 4893 | 3308 | 123.0 | 217.6 | 214.5 | 1161.5 | 705.4 | 361.5 | 947 | 38.17 | 35.72 |
| 13 | 5 | 18.2 | 120 | 2.44 | 0.1794 | 0.1685 | 3.816 | 51.90 | | 660 | 1140 | 4680 | 3114 | 122.0 | 216.8 | 214.4 | 1084.4 | 651.3 | 338.4 | 870 | 38.89 | 36.38 |
| 14 | 5 | 20.5 | 135 | 2.64 | 0.1783 | 0.1502 | 3.864 | 52.06 | | 660 | 1151 | 4433 | 2891 | 121.4 | 216.9 | 214.8 | 994.8 | 588.8 | 310.5 | 780 | 39.80 | 37.18 |
| 15 | 5 | 22.8 | 150 | 2.91 | 0.1776 | 0.1363 | 3.878 | 52.22 | | 660 | 1157 | 4207 | 2693 | 120.5 | 216.1 | 214.0 | 919.0 | 537.1 | 286.4 | 705 | 40.62 | 38.03 |
| 16 | 6 | 15.2 | 100 | 1.56 | 0.1806 | 0.2011 | 3.782 | 51.50 | | 660 | 1188 | 5219 | 3446 | 123.7 | 230.4 | 227.2 | 1287.2 | 750.2 | 430.3 | 1060 | 40.60 | 37.92 |
| 17 | 6 | 16.7 | 110 | 1.75 | 0.1789 | 0.1840 | 3.801 | 51.76 | | 660 | 1196 | 4500 | 3236 | 122.4 | 231.1 | 228.4 | 1196.4 | 687.0 | 400.7 | 968 | 41.39 | 38.71 |
| 18 | 6 | 18.2 | 120 | 1.96 | 0.1794 | 0.1684 | 3.840 | 51.85 | | 660 | 1204 | 4785 | 3042 | 122.5 | 230.5 | 227.2 | 1117.2 | 633.7 | 375.5 | 890 | 42.19 | 39.44 |
| 19 | 6 | 20.5 | 135 | 2.04 | 0.1785 | 0.1517 | 3.873 | 52.05 | | 660 | 1218 | 4544 | 2826 | 121.5 | 230.5 | 227.4 | 1027.4 | 573.5 | 345.0 | 800 | 43.12 | 40.35 |
| 20 | 6 | 22.8 | 150 | 2.28 | 0.1776 | 0.1371 | 3.897 | 52.18 | | 660 | 1227 | 4315 | 2630 | 120.6 | 230.2 | 227.6 | 949.6 | 522.7 | 317.3 | 722 | 43.94 | 41.15 |

[1] Lower heating value = 18,830 B.t.u. per lb. Higher heating value = 20,150 B.t.u. per lb.
Composition by weight, 100 per cent $C_8H_{18}$.

TABLE 4 CALCULATED RESULTS FOR IDEAL OTTO ENGINE WITH "90 PER CENT" BENZOL[1] AS FUEL

| Case number | Compression ratio | Lb. air per lb. fuel | Per cent air | Lb. residual gas per lb. fuel | Gas constants for fuel mixture: $M$ | $B(10)^4$ | $C(10)^9$ | $R$ | Gas constants for products mixture | Abs. temperatures, deg. fahr.: Beginning of compression $T_1$ | End of compression $T_2$ | Beginning of expansion $T_3$ | End of expansion $T_4$ | Internal energies, B.t.u. per lb. mixture: Fuel mixture: Beginning of compression $i_1$ | End of compression $i_2$ | Products mixture: End of compression $i_2'$ | Beginning of expansion $i_3$ | End of expansion $i_4$ | Net work, B.t.u. per lb. mixture $\text{Work}_i$ | Heat supplied, B.t.u. per lb. mixture based on lower h. v. $Q_i$ | Efficiencies, per cent: Based on lower h. v. $e_i$ | Based on higher h. v. $e_i'$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 3 | 13.48 | 100 | 3.59 | 0.1636 | 0.2555 | 3.316 | 51.48 | See Table 2 | 660 | 994 | 4967 | 3840 | 113.9 | 176.4 | 180.9 | 1149.6 | 826.4 | 260.7 | 968.7 | 26.91 | 25.81 |
| 22 | 3 | 20.22 | 150 | 5.30 | 0.1655 | 0.1737 | 3.589 | 52.31 | | 660 | 998 | 3992 | 2950 | 113.4 | 175.0 | 179.0 | 839.0 | 583.9 | 193.4 | 660.0 | 29.31 | 28.15 |
| 23 | 4 | 13.48 | 100 | 2.41 | 0.1630 | 0.2600 | 3.478 | 51.44 | | 660 | 1076 | 5232 | 3799 | 113.6 | 191.8 | 196.7 | 1233.1 | 815.4 | 339.5 | 1036.4 | 32.75 | 31.43 |
| 24 | 4 | 16.18 | 120 | 2.82 | 0.1643 | 0.2183 | 3.579 | 51.79 | | 660 | 1084 | 4769 | 3370 | 113.5 | 192.4 | 196.6 | 1071.4 | 693.8 | 298.8 | 874.8 | 34.15 | 32.76 |
| 25 | 5 | 13.48 | 100 | 1.84 | 0.1627 | 0.2613 | 3.565 | 51.39 | | 660 | 1159 | 5393 | 3726 | 113.4 | 208.0 | 212.9 | 1285.4 | 796.2 | 394.6 | 1072.5 | 36.79 | 35.23 |
| 26 | 5 | 16.18 | 120 | 2.16 | 0.1641 | 0.2207 | 3.640 | 51.78 | | 660 | 1171 | 4926 | 3298 | 113.5 | 209.3 | 213.5 | 1118.4 | 676.1 | 346.4 | 904.9 | 38.28 | 36.76 |
| 27 | 5 | 20.22 | 150 | 2.62 | 0.1658 | 0.1783 | 3.758 | 52.26 | | 660 | 1184 | 4399 | 2835 | 113.7 | 210.9 | 214.2 | 948.2 | 557.5 | 293.5 | 734.0 | 39.99 | 38.37 |
| 28 | 6 | 13.48 | 100 | 1.43 | 0.1624 | 0.2626 | 3.623 | 51.45 | | 660 | 1235 | 5521 | 3663 | 113.2 | 222.8 | 227.8 | 1327.8 | 779.8 | 438.4 | 1100.0 | 39.86 | 38.19 |
| 29 | 6 | 16.18 | 120 | 1.68 | 0.1638 | 0.2216 | 3.700 | 51.75 | | 660 | 1246 | 5046 | 3232 | 113.3 | 223.8 | 227.1 | 1155.1 | 660.1 | 384.5 | 928.0 | 41.44 | 39.73 |
| 30 | 7 | 13.48 | 100 | 1.22 | 0.1623 | 0.2638 | 3.666 | 51.38 | | 660 | 1296 | 5601 | 3586 | 113.2 | 235.1 | 239.9 | 1354.5 | 759.8 | 472.8 | 1114.6 | 42.42 | 40.69 |
| 31 | 7 | 16.18 | 120 | 1.23 | 0.1638 | 0.2246 | 3.734 | 51.74 | | 660 | 1311 | 5162 | 3188 | 113.4 | 236.8 | 240.7 | 1191.2 | 649.5 | 418.2 | 950.5 | 44.00 | 42.25 |
| 32 | 7 | 20.22 | 150 | 1.76 | 0.1655 | 0.1797 | 3.824 | 52.27 | | 660 | 1331 | 4598 | 2707 | 113.5 | 239.2 | 242.5 | 1004.1 | 528.7 | 349.7 | 761.6 | 45.91 | 44.04 |

[1] Lower heating value = 17,500 B.t.u. per lb. Higher heating value = 18,240 B.t.u. per lb.
Composition by weight 73 per cent $C_6H_6$, 23 per cent $C_7H_8$, 4 per cent $C_8H_{10}$.

TABLE 5 CALCULATED RESULTS FOR IDEAL OTTO ENGINE, BLAST-FURNACE GAS[1] AS FUEL

| Case number | Compression ratio | Lb. air per lb. fuel | Per cent air | Lb. residual gas per lb. fuel | Gas constants for fuel mixture: $M$ | $B(10)^4$ | $C(10)^9$ | $R$ | Gas constants for products mixture | Abs. temperatures, deg. fahr.: Beginning of compression $T_1$ | End of compression $T_2$ | Beginning of expansion $T_3$ | End of expansion $T_4$ | Internal energies, B.t.u. per lb. mixture: Fuel mixture: Beginning of compression $i_1$ | End of compression $i_2$ | Products mixture: End of compression $i_2'$ | Beginning of expansion $i_3$ | End of expansion $i_4$ | Net work, B.t.u. per lb. mixture $\text{Work}_i$ | Heat supplied, B.t.u. per lb. mixture, based on lower h. v. $Q_i$ | Efficiencies, per cent: Based on lower h. v. $e_i$ | Based on higher h. v. $e_i'$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 6 | 0.744 | 100 | 0.186 | 0.1705 | 0.1009 | 2.285 | 53.24 | See Table 2 | 660 | 1296 | 4238 | 2669 | 115.0 | 230.9 | 229.5 | 903.1 | 519.5 | 267.8 | 673.6 | 39.75 | 39.15 |
| 34 | 6 | 0.893 | 120 | 0.199 | 0.1706 | 0.0931 | 2.432 | 53.37 | | 660 | 1300 | 4060 | 2516 | 114.9 | 231.4 | 230.2 | 851.5 | 482.8 | 252.1 | 621.3 | 40.57 | 40.00 |
| 35 | 6 | 1.042 | 140 | 0.217 | 0.1706 | 0.0864 | 2.556 | 53.37 | | 660 | 1302 | 3895 | 2382 | 114.7 | 231.2 | 229.8 | 805.3 | 451.4 | 237.4 | 575.5 | 41.26 | 40.64 |
| 36 | 7 | 0.744 | 100 | 0.156 | 0.1706 | 0.0980 | 2.340 | 53.31 | | 660 | 1371 | 4333 | 2625 | 115.1 | 244.7 | 244.3 | 928.5 | 509.5 | 289.4 | 684.2 | 42.29 | 41.65 |
| 37 | 7 | 0.893 | 120 | 0.167 | 0.1707 | 0.0905 | 2.486 | 53.43 | | 660 | 1375 | 4154 | 2473 | 114.9 | 245.2 | 244.7 | 875.8 | 473.3 | 272.2 | 631.1 | 43.14 | 42.49 |
| 38 | 7 | 1.042 | 140 | 0.181 | 0.1708 | 0.0838 | 2.607 | 53.43 | | 660 | 1377 | 3988 | 2340 | 114.8 | 245.1 | 244.2 | 828.8 | 442.4 | 256.1 | 584.7 | 43.81 | 43.15 |
| 39 | 8 | 0.744 | 100 | 0.134 | 0.1708 | 0.0959 | 2.378 | 53.37 | | 660 | 1440 | 4413 | 2585 | 115.1 | 257.8 | 257.9 | 950.0 | 500.4 | 306.9 | 692.1 | 44.34 | 43.67 |
| 40 | 8 | 0.893 | 120 | 0.146 | 0.1709 | 0.0887 | 2.520 | 53.48 | | 660 | 1445 | 4230 | 2431 | 115.0 | 258.8 | 258.3 | 895.9 | 464.1 | 287.9 | 637.6 | 45.16 | 44.48 |
| 41 | 8 | 1.042 | 140 | 0.159 | 0.1709 | 0.0819 | 2.641 | 53.49 | | 660 | 1448 | 4068 | 2303 | 114.8 | 258.8 | 258.7 | 849.4 | 434.4 | 271.1 | 590.7 | 45.89 | 45.20 |
| 42 | 9 | 0.744 | 100 | 0.120 | 0.1709 | 0.0942 | 2.416 | 53.42 | | 660 | 1506 | 4478 | 2545 | 115.2 | 270.5 | 270.1 | 967.6 | 491.6 | 320.7 | 697.5 | 45.98 | 45.30 |
| 43 | 9 | 0.893 | 120 | 0.128 | 0.1710 | 0.0870 | 2.556 | 53.51 | | 660 | 1509 | 4301 | 2398 | 115.0 | 270.8 | 271.5 | 914.6 | 456.8 | 302.0 | 643.1 | 46.96 | 46.25 |
| 44 | 9 | 1.042 | 140 | 0.138 | 0.1710 | 0.0805 | 2.672 | 53.51 | | 660 | 1512 | 4133 | 2267 | 114.9 | 270.5 | 271.0 | 867.2 | 426.6 | 285.0 | 596.2 | 47.80 | 47.08 |

[1] Lower heating value = 98 B.t.u. per cu. ft. or 1300 B.t.u. per lb. Higher heating value = 99.5 B.t.u. per cu. ft. or 1318 B.t.u. per lb.
Composition by volume 28 per cent CO, 3 per cent $H_2$, 10 per cent $CO_2$, 59 per cent $N_2$.
Composition by weight 27.2 per cent CO, 0.2 per cent $H_2$, 15.2 per cent $CO_2$, 57.4 per cent $N_2$.

same percentage of air. For the gasoline and "90 per cent benzol" the curves are almost identical when taken for the same weight of air per pound of fuel and for the same compression ratio. In all cases the efficiency is increased by a high compression ratio and a high percentage of air.

The ideal cycle efficiencies are drawn for both the higher and lower heating values of the fuel because sometimes one and sometimes the other is needed, for the present at least, when used as the proper standard with which the thermal efficiency of an actual engine may be compared. The engineer knows that he cannot build an internal-combustion engine that does not waste some energy to the water jacket, some to mechanical and fluid friction, and sometimes an excessive amount to the exhaust. (The term fluid friction refers to the resistances that must be overcome in getting the working substance in and out of the cylinder.) Naturally the designer and owner of an engine desire to know to what degree they have succeeded in eliminating these combined losses. The only way to do this is to determine the ratio that is now called by the A.S.M.E. Test Code on Definitions and Values the "engine efficiency." This term seems to be an excellent one because it represents a ratio that tells exactly how well the actual engine succeeds in converting the available energy of the fuel into useful work at the brake. This available energy, as previously explained, can never be based logically on anything but the lower heating value for the internal-combustion motor. However, both the ideal and actual engine may be arbitrarily charged with the higher heating value by any engineer who desires to base his thermal efficiency upon it. Consequently the two heating values may be involved in expressing engine performance, and there result the following equations:

Engine efficiency

$$= \frac{\text{Brake thermal effy. of actual engine based on L.H.V.}}{\text{Ideal cycle efficiency based on L.H.V.}} \quad [32a]$$

$$= \frac{\text{Brake thermal effy. of actual engine based on H.H.V.}}{\text{Ideal cycle efficiency based on H.H.V.}} \quad [32b]$$

$$= \frac{\text{Fuel required by ideal engine, lb. per hp-hr.}}{\text{Fuel used by actual engine, lb. per b.hp-hr.}} \quad [32c]$$

As an illustration of the application of these equations, consider the following typical example:

Assume an Otto engine with a compression ratio of 5, using 0.5 lb. of gasoline per b.hp-hr., and 10 per cent more air than that required for complete combustion of the fuel. Consider the two heating values of the fuel to be as given at the bottom of Table 3. From this table it may be seen that case No. 12 fulfils the required conditions, and that the efficiencies of the ideal engine are 38.2 and 35.7 per cent for the lower and higher heating values, respectively. Then from Equation [32*a*],

$$\text{Engine effy.} = \frac{2545/(0.5 \times 18{,}830)}{0.382} = \frac{0.27}{0.382} = 0.708$$

also from Equation [32*b*],

$$\text{Engine effy.} = \frac{2545/(0.5 \times 20{,}150)}{0.357} = \frac{0.253}{0.357} = 0.708$$

This same result will also be obtained by using Equation [32c], but it can not be found in quite such a direct manner. Thus for case 12, Table 3, it is observed that the net work per pound of mixture is 361.5 B.t.u. and this mixture is made up of 16.7 lb. of air and 2.18 lb. of residual gases per pound of fuel. Consequently the net work per pound of fuel in the ideal engine would be

$$361.5(16.7 + 2.18 + 1) = 7190 \text{ B.t.u.}$$

Hence the fuel required by such an engine would be

$$\frac{2545}{7190} = 0.354 \text{ lb. per hp-hr.}$$

Then from Equation [32*c*],

$$\text{Engine efficiency} = \frac{0.354}{0.5} = 0.708$$

It should be particularly noted that each of the three results for the engine efficiency is the same regardless of which heating value is chosen as the base on which the thermal efficiency is calculated, an important point for this method of measuring performance.

This measure of the performance of an internal-combustion engine is, in the opinion of the authors, one of the best to use in most of our engineering and public discussions. Why should the layman be continuously confronted with highly technical terms which he does not understand and which are positively misleading to him? He may never understand either thermal or engine efficiency, but when either one is presented to him he instinctively thinks of how near it is to 100 per cent. Thus he thinks that an engine that has a thermal efficiency of 30 per cent is a very poor example of the mechanical engineer's art, whereas if he is told that the engine efficiency is 75 per cent he naturally feels that the machine is a much better one. This is especially true if this layman has purchased from the same mechanical engineer a water wheel whose only "efficiency" is given as 85 per cent. As a matter of fact, the portion of the available energy that has been utilized by the actual internal-combustion motor or water wheel is an excellent measure of performance for both the engineer and the layman, because it indicates at once what the possible margin of future improvement actually is, while the thermal efficiency does not. In the past, the lack of sufficient reliable data regarding variable specific heats has been a serious difficulty in the way of obtaining the available energy, but now this question seems to be fairly well answered. Consequently, is there any good reason why engine efficiencies and fuel consumption per brake horsepower-hour should not be used as the chief means of expressing the performance of internal-combustion engines?

TABLE 6 GAS CONSTANTS FOR COMPRESSION MIXTURE IN DIESEL USING PETROLEUM OIL

| Case No. | Compression ratio | Lb. air per lb. fuel | Per cent air | $M'$ | $M$ | $B(10)^*$ | $C(10)^*$ | $R$ |
|---|---|---|---|---|---|---|---|---|
| 45 | 12 | 20 | 139 | 0.2407 | 0.1720 | 0.5562 | 4.100 | 53.5 |
| 46 | 12 | 30 | 208 | 0.2406 | 0.1719 | 0.3810 | 4.120 | 53.5 |
| 47 | 12 | 40 | 278 | 0.2405 | 0.1719 | 0.2817 | 4.136 | 53.4 |
| 48 | 12 | 60 | 417 | 0.2404 | 0.1718 | 0.1891 | 4.144 | 53.4 |
| 49 | 12 | 80 | 555 | 0.2403 | 0.1718 | 0.1418 | 4.152 | 53.3 |
| 50 | 12 | 100 | 695 | 0.2403 | 0.1718 | 0.1133 | 4.153 | 53.3 |
| 51 | 13 | 20 | 139 | 0.2407 | 0.1720 | 0.5222 | 4.105 | 53.5 |
| 52 | 13 | 40 | 278 | 0.2405 | 0.1719 | 0.2610 | 4.138 | 53.4 |
| 53 | 13 | 60 | 417 | 0.2404 | 0.1719 | 0.1670 | 4.147 | 53.3 |
| 54 | 13 | 80 | 555 | 0.2403 | 0.1718 | 0.1310 | 4.152 | 53.3 |
| 55 | 14 | 20 | 139 | 0.2406 | 0.1719 | 0.4828 | 4.110 | 53.5 |
| 56 | 14 | 40 | 278 | 0.2405 | 0.1719 | 0.2415 | 4.141 | 53.4 |
| 57 | 14 | 60 | 417 | 0.2404 | 0.1719 | 0.1610 | 4.148 | 53.3 |
| 58 | 14 | 80 | 555 | 0.2403 | 0.1718 | 0.1212 | 4.154 | 53.3 |
| 59 | 15 | 20 | 139 | 0.2406 | 0.1719 | 0.4462 | 4.113 | 53.5 |
| 60 | 15 | 40 | 278 | 0.2405 | 0.1719 | 0.2246 | 4.147 | 53.4 |
| 61 | 15 | 80 | 555 | 0.2403 | 0.1718 | 0.1128 | 4.154 | 53.3 |
| 62 | 16 | 20 | 139 | 0.2406 | 0.1719 | 0.4214 | 4.116 | 53.5 |
| 63 | 16 | 40 | 278 | 0.2405 | 0.1719 | 0.2106 | 4.143 | 53.4 |
| 64 | 16 | 80 | 555 | 0.2403 | 0.1718 | 0.1055 | 4.155 | 53.3 |
| 65 | 16 | 100 | 695 | 0.2403 | 0.1718 | 0.0842 | 4.155 | 53.3 |

The results of calculations for the Otto cycle using gasoline, with 100 and 120 per cent air, have been plotted in Fig. 6 with the compression ratios as abscissas. There has also been added to these figures the curves which represent the results obtained by solving the familiar equation for the efficiency, $e = 1 - (1/r)^{\gamma - 1}$ where $\gamma$ represents the ratio $c_p/c_v$ of the specific heats of the working substance. Thus if $\gamma$ be taken as 1.4 this equation will

yield the efficiency curve marked "cold-air standard," because this value of $\gamma$ is only true for air when at the relatively low temperature of from about 0 to 400 deg. fahr. Since the average temperature in the Otto engine is far above these values, it is not surprising to see the curves representing the efficiencies based on this value lying far above the more reliable ones in this same figure. In this latter group are drawn in heavy lines the curves showing the efficiencies obtained by calculations involving the variable specific heats of the mixture corresponding to that in the actual engine. These curves may therefore, it seems to the authors, very properly be designated as those based on the "real-mixture standard."

In Fig. 6 there are also the curves giving the efficiencies calculated by the equation, $e = 1 - (1/r)^{\gamma - 1}$, in which the value of $\gamma$ is chosen to give efficiencies that agree fairly well with the real-mixture standard. This simply means determining a suitable average value of $\gamma$ for the entire cycle corresponding to hot air instead of cold air, and consequently it seems logical to the authors to refer to these curves as "hot-air standards." It is seen from Fig. 6 that with $\gamma = 1.295$, the resultant curve is in fairly close agreement with the one representing the real-mixture standard based on the lower heating value of gasoline with a small amount of excess air. For the compression ratios above 4, a value of $\gamma = 1.29$ will be in better agreement with this real-mixture standard for 100 per cent air.

When the higher heating value of gasoline is used, the curves in Fig. 6 show that a value of $\gamma$ = 1.265 or 1.27 would be more suitable. It may be observed that the shape of the efficiency curve for the real-mixture standard is slightly different from those of the air standards.

For blast-furnace gas the results are given in Fig. 7, which shows the same general characteristics as those discussed for gasoline. It will be noticed at once that for this fuel the difference between the two efficiencies based upon the two heating values becomes slight because the amount of hydrogen involved in blast-furnace gas is so small. With $\gamma = 1.28$ the hot-air standard is seen to agree very closely with the real-mixture standard based on the higher heating value and 100 per cent air, while for the same standard on the lower heating value, the agreement is close if $\gamma$ is chosen as 1.275.

For the ideal Diesel engine the results obtained by calculations of the efficiencies for the real-mixture standard with petroleum oil are given in Table 8, and also in Fig. 8. These efficiencies are higher than for the Otto solely because they have been calculated for higher compression ratios and with more air per unit weight of fuel than was done for the Otto. A basic advantage of the Diesel engine over the Otto, as far as thermal economy is concerned, is due to the fact that the former can operate satisfactorily with very much higher compression ratios and a higher air-to-fuel ratio than the latter. The Diesel engine so seldom operates without considerable excess air that it was not considered worth while to calculate the ideal efficiencies for less than 20 pounds of air per pound of fuel, or in other words, for about 40 per cent excess air. On the other hand, when the Diesel is running at very light loads the air-fuel ratio is extremely high

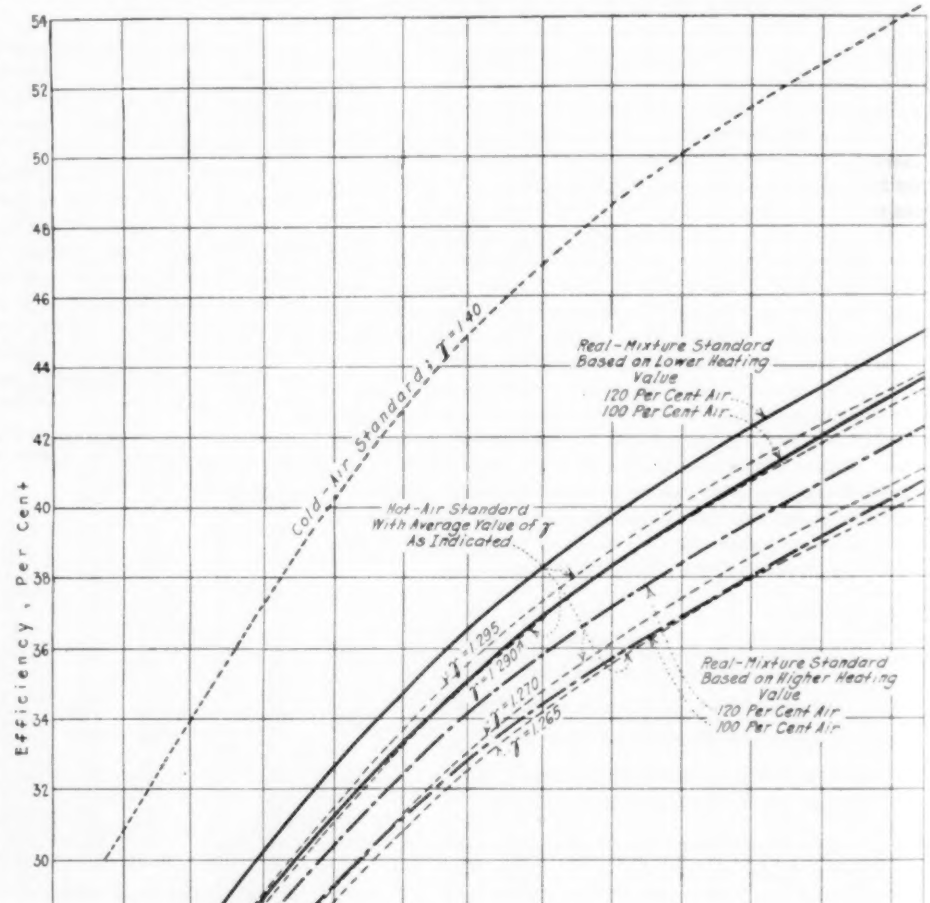


Fig. 6 Effect of Different Standards on the Efficiencies of the Ideal Otto Engine Using Gasoline

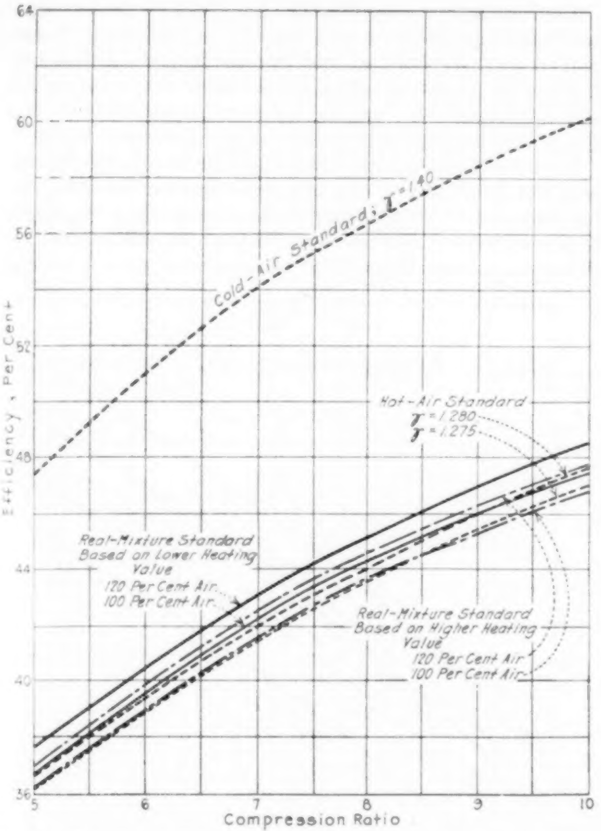


FIG. 7 EFFECT OF DIFFERENT STANDARDS ON THE EFFICIENCIES OF THE IDEAL OTTO ENGINE USING BLAST-FURNACE GAS

and the calculations were, therefore, carried to 100 pounds of air per pound of fuel, which corresponds to nearly seven times as much air as is required for complete combustion.

In the Diesel, for any given compression ratio a large proportion of air to fuel simply means early cut-off of the fuel injection and consequently a greater expansion of the products of combustion. This greater expansion is the primary reason for the marked increase in the ideal cycle efficiency shown in Fig. 8, as the air-fuel ratio becomes larger. A secondary reason is that with the greater weights of air used per unit weight of fuel the

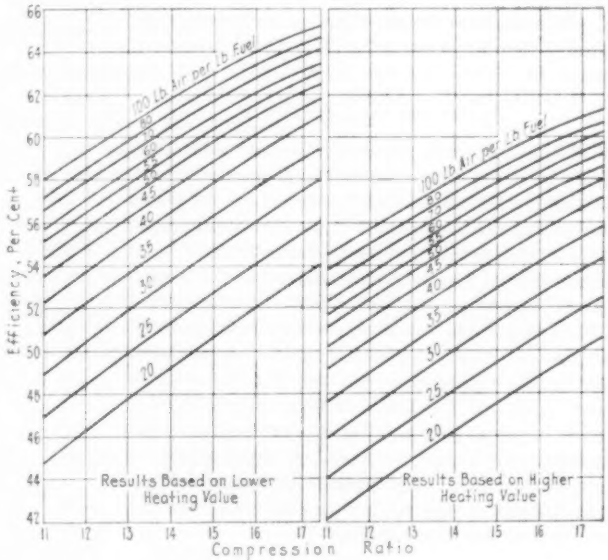


FIG. 8 EFFICIENCY OF IDEAL DIESEL ENGINE USING PETROLEUM OIL

TABLE 7 GAS CONSTANTS FOR EXPANSION MIXTURE IN DIESEL USING PETROLEUM OIL

| Lb. air per lb. fuel | Per cent air | $M'$ ($T>2900$) | $M_0'$ ($T<2900$) | $M$ ($T>2900$) | $M_0$ ($T<2900$) | $B(10)^6$ ($T>2900$) | $B_0(10)^6$ ($T<2900$) | $C(10)^9$ ($T>2900$) | $C_0(10)^9$ ($T<2900$) | $R$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 139 | 0.2620 | 0.2448 | 0.1938 | 0.1766 | 0.0592 | 1.255 | 4.680 | 2.621 | 53.1 |
| 30 | 208 | 0.2552 | 0.2435 | 0.1869 | 0.1752 | 0.0393 | 0.8423 | 4.521 | 3.135 | 53.1 |
| 40 | 278 | 0.2517 | 0.2429 | 0.1833 | 0.1745 | 0.0297 | 0.6363 | 4.430 | 3.380 | 53.2 |
| 60 | 417 | 0.2478 | 0.2419 | 0.1794 | 0.1735 | 0.0198 | 0.4284 | 4.341 | 3.642 | 53.2 |
| 80 | 555 | 0.2459 | 0.2415 | 0.1774 | 0.1730 | 0.0149 | 0.3219 | 4.301 | 3.771 | 53.3 |
| 100 | 695 | 0.2448 | 0.2412 | 0.1763 | 0.1727 | 0.0120 | 0.2582 | 4.276 | 3.850 | 53.3 |

TABLE 8 CALCULATED RESULTS FOR IDEAL DIESEL ENGINE USING PETROLEUM OIL[1]

| | | | | | Abs. temperatures, deg. fahr. | | | | Compression mixture | | Products mixture | | | | | | | | Efficiencies, per cent | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Case number | Compression ratio $r$ | Lb. air per lb. fuel | Per cent air | Lb. residual gas per lb. fuel | Beginning of compression $T_1$ | End of compression $T_2$ | Beginning of expansion $T_3$ | End of expansion $T_4$ | Internal energy at beginning of compression, B.t.u. per lb. mixture $i_1$ | Enthalpy at end of compression, B.t.u. per lb. mixture $h_2$ | Enthalpy at $T_2$ and $P_2$ B.t.u. per lb. mixture $h_2'$ | Enthalpy at beginning of expansion, B.t.u. per lb. mixture $h_3$ | Internal energy at end of expansion, B.t.u. per lb. mixture $i_4$ | Cut-off ratio $V_3/V_2$ | Expansion ratio $V_4/V_3$ | Ratio by wt., compression mixture to products mixture $w_1/w_4$ | Net work, B.t.u. per lb. products mixture $Work_i$ | Heat supplied based on lower h. v., B.t.u. per lb. products mixt. $Q_i$ | Based on lower h. v. $e_i$ | Based on higher h. v. $e_i'$ |
| 45 | 12 | 20 | 139 | 0.99 | 660 | 1730 | 4404 | 2949 | 114.0 | 423.9 | 446.3 | 1276.3 | 597.9 | 2.630 | 4.513 | 0.9545 | 382.6 | 830 | 46.10 | 43.19 |
| 46 | 12 | 30 | 208 | 1.42 | 660 | 1731 | 3669 | 2181 | 114.0 | 424.0 | 439.5 | 1002.0 | 412.9 | 2.160 | 5.504 | 0.9692 | 288.6 | 563 | 51.25 | 48.01 |
| 47 | 12 | 40 | 278 | 1.94 | 660 | 1733 | 3249 | 1787 | 114.0 | 424.6 | 436.4 | 861.4 | 329.8 | 1.900 | 6.268 | 0.9767 | 228.2 | 425 | 53.70 | 50.31 |
| 48 | 12 | 60 | 417 | 2.81 | 660 | 1738 | 2793 | 1392 | 113.9 | 425.5 | 432.8 | 718.8 | 248.9 | 1.620 | 7.357 | 0.9843 | 163.2 | 286 | 57.06 | 53.46 |
| 49 | 12 | 80 | 555 | 3.69 | 660 | 1738 | 2546 | 1198 | 113.9 | 425.5 | 430.5 | 645.9 | 211.8 | 1.472 | 8.111 | 0.9882 | 126.2 | 215.5 | 58.57 | 54.87 |
| 50 | 12 | 100 | 695 | 4.80 | 660 | 1739 | 2389 | 1082 | 113.8 | 425.5 | 428.7 | 601.2 | 190.1 | 1.380 | 8.661 | 0.9906 | 102.4 | 172.5 | 59.35 | 55.60 |
| 51 | 13 | 20 | 139 | 0.88 | 660 | 1781 | 4456 | 2908 | 114.0 | 436.6 | 460.7 | 1294.7 | 588.2 | 2.580 | 4.974 | 0.9543 | 398.8 | 834 | 47.81 | 44.79 |
| 52 | 13 | 40 | 278 | 1.74 | 660 | 1787 | 3301 | 1762 | 114.0 | 438.3 | 450.2 | 877.2 | 324.9 | 1.877 | 6.888 | 0.9766 | 235.6 | 427 | 55.17 | 51.69 |
| 53 | 13 | 60 | 417 | 2.48 | 660 | 1792 | 2848 | 1375 | 113.9 | 439.2 | 441.9 | 734.3 | 245.9 | 1.600 | 8.069 | 0.9843 | 168.2 | 287.5 | 58.51 | 54.82 |
| 54 | 13 | 80 | 555 | 3.41 | 660 | 1795 | 2603 | 1188 | 113.9 | 440.2 | 445.5 | 661.8 | 210.0 | 1.457 | 8.870 | 0.9881 | 129.4 | 216.2 | 59.85 | 56.07 |
| 55 | 14 | 20 | 139 | 0.83 | 660 | 1835 | 4501 | 2864 | 114.0 | 451.3 | 475.0 | 1311.0 | 578.0 | 2.535 | 5.465 | 0.9542 | 411.2 | 836 | 49.19 | 46.08 |
| 56 | 14 | 40 | 278 | 1.64 | 660 | 1840 | 3351 | 1739 | 114.0 | 451.5 | 464.3 | 892.3 | 320.3 | 1.850 | 7.523 | 0.9765 | 242.3 | 428 | 56.61 | 53.04 |
| 57 | 14 | 60 | 417 | 2.30 | 660 | 1844 | 2900 | 1361 | 113.9 | 452.7 | 460.9 | 749.1 | 243.3 | 1.590 | 8.777 | 0.9842 | 172.3 | 288.3 | 59.77 | 56.00 |
| 58 | 14 | 80 | 555 | 3.10 | 660 | 1845 | 2655 | 1177 | 113.9 | 453.4 | 458.9 | 675.9 | 207.9 | 1.447 | 9.639 | 0.9881 | 132.5 | 217 | 61.06 | 57.20 |
| 59 | 15 | 20 | 139 | 0.78 | 660 | 1878 | 4539 | 2825 | 114.0 | 461.9 | 486.9 | 1324.8 | 568.7 | 2.500 | 5.939 | 0.9541 | 424.2 | 838 | 50.62 | 47.42 |
| 60 | 15 | 40 | 278 | 1.44 | 660 | 1888 | 3400 | 1719 | 114.0 | 463.7 | 476.9 | 906.9 | 316.6 | 1.825 | 8.156 | 0.9764 | 248.8 | 430 | 57.87 | 54.22 |
| 61 | 15 | 80 | 555 | 2.72 | 660 | 1902 | 2707 | 1168 | 113.9 | 466.7 | 472.4 | 690.4 | 206.4 | 1.435 | 10.429 | 0.9881 | 135.5 | 218 | 62.16 | 58.23 |
| 62 | 16 | 20 | 139 | 0.73 | 660 | 1923 | 4582 | 2791 | 114.0 | 473.0 | 500.4 | 1340.4 | 560.9 | 2.470 | 6.422 | 0.9540 | 437.0 | 840 | 52.03 | 48.74 |
| 63 | 16 | 40 | 278 | 1.25 | 660 | 1932 | 3441 | 1699 | 113.9 | 474.3 | 488.0 | 919.5 | 312.6 | 1.815 | 8.793 | 0.9764 | 255.0 | 432 | 59.03 | 55.30 |
| 64 | 16 | 80 | 555 | 2.52 | 660 | 1941 | 2748 | 1157 | 113.9 | 477.3 | 483.2 | 701.7 | 204.4 | 1.420 | 11.184 | 0.9880 | 138.3 | 218.5 | 63.28 | 59.28 |
| 65 | 16 | 100 | 695 | 3.29 | 660 | 1943 | 2596 | 1054 | 113.8 | 477.8 | 482.5 | 657.5 | 184.9 | 1.345 | 11.865 | 0.9904 | 112.1 | 175 | 64.03 | 59.99 |

[1] Composition by weight, 86 per cent C, 13 per cent H, 1 per cent N; lower heating value = 18,250 B.t.u. per lb., higher heating value = 19,480 B.t.u. per lb.

higher will be the average value of $\gamma$ during the expansion, and consequently the smaller becomes the temperature $T_4$ for a given expansion ratio, just as in the Otto. Of course it is desirable to have $T_4$ as low as possible in order to reduce the energy lost to the exhaust.

It was not considered worth while to plot the results for the Diesel in any form other than that given in Fig. 8 because it is believed this will be found to be the most convenient arrangement for general use. The performance test of a Diesel engine should give the specific fuel consumption and the corresponding air-fuel ratio. The compression ratio is known for any given engine, consequently the engine efficiency may be readily found by the aid of Fig. 8 and Equation [32].

### Mean Effective Pressures

If it be desired to determine the mean effective pressure of the ideal Otto or Diesel engine for any of the 65 cases calculated, it may be readily done in the following manner. From the appropriate table of calculated results read the net work $\text{Work}_i$ accomplished by the ideal engine in B.t.u. per pound of product mixture. Then the piston displacement, P.D., necessary to handle this pound of product mixture depends upon the constant $R_1$ for the compression mixture, the initial pressure $p_1$, the initial absolute temperature $T_1$, the ratio of compression $r$, and the weight of compression mixture $w_1$ required for each pound of product mixture. Referring to Fig. 2, it follows that the piston displacement in cubic feet required per pound of product mixture is

$$\text{P.D.} = V_4 - V_3 = V_1 - V_2 = V_1\left[1 - \frac{1}{r}\right]$$

$$= \frac{w_1 R_1 T_1}{144 p_1}\left[1 - \frac{1}{r}\right] \qquad [33]$$

Consequently the mean effective pressure of the ideal engine in pounds per square inch is

$$p_m = \frac{778 \times \text{Work}_i}{144\ \text{P.D.}} = \frac{778 \times \text{Work}_i(p_1)}{w_1 R_1 T_1\left[1 - \dfrac{1}{r}\right]} \qquad [34]$$

In this equation the value of $p_1$ should be chosen to agree with the atmospheric pressure at the time and place at which the actual engine is being tested, and $T_1$ should equal the assumed value for the ideal cycle calculations. Under these conditions the engine efficiency is also equal to the ratio of the brake m.e.p. of the actual engine to that of the corresponding ideal.

### Comparison with Results of Goodenough and Baker

After the calculations given in this paper for the ideal Otto and Diesel cycles had been almost completed, there became available the valuable bulletin[6] by Goodenough and Baker, entitled "A Thermodynamic Analysis of Internal-Combustion-Engine Cycles." Since this bulletin deals largely with the same questions that are treated in this paper, and since the same specific-heat equations are used in both cases, a brief discussion of the main points of difference in the conceptions of the ideal cycles and in the results obtained from the calculations will be given.

[6] Bulletin No. 160, University of Illinois, 1927.

The assumptions regarding the ideal cycles for the two sets of calculations are not alike with regard to air deficiency, dissociation, initial temperature, and the amount of residual gases. Also, for the Diesel, Goodenough and Baker have considered the fuel to be completely vaporized before entering the cylinder, while the authors have assumed the fuel to be injected as a liquid.

From Fig. 9 it may be seen that the difference in the efficiencies obtained from the two sets of calculations for the Otto varies from about 1.5 to 2 per cent, for the case in which the air used is 100 per cent of that necessary to support combustion. The difference becomes less and less as the air-fuel ratio is increased

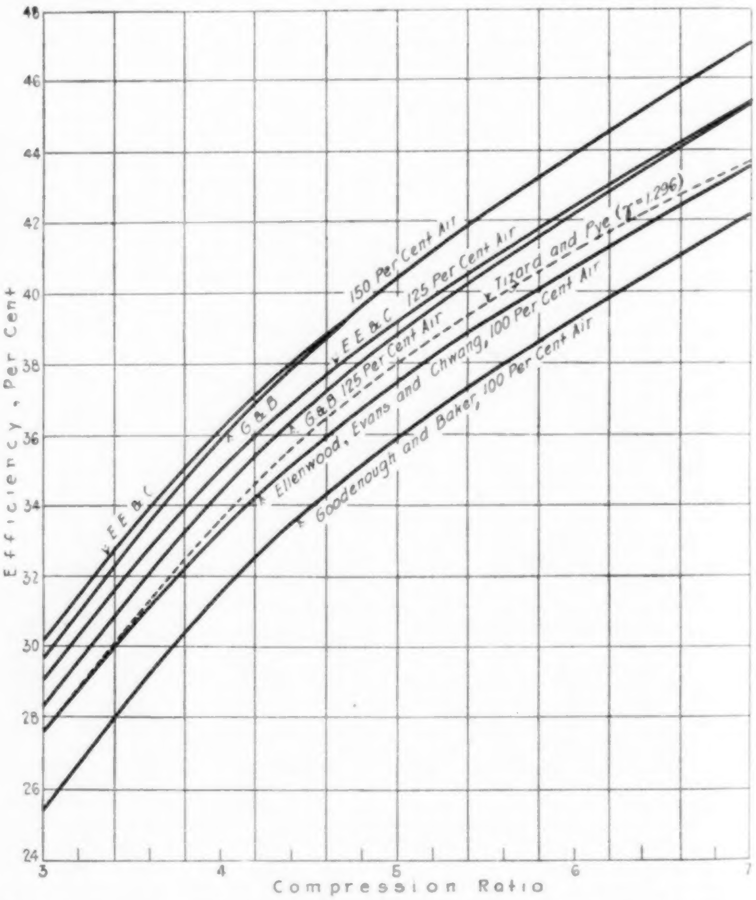


Fig. 9 Comparative Results for the Otto Engine Using Gasoline (Lower Heating Value)

until it is negligibly small at 150 per cent air, as shown by the two upper curves. For cases involving a deficiency of air the comparison cannot be made because this paper does not include them for reasons already given.

In Fig. 9 there is also shown by the broken line the curve of efficiencies obtained by using the equation $e = 1 - (1/r)^{\gamma - 1}$ where $\gamma$ is taken as equal to 1.296. This represents the equation proposed by Tizard and Pye[7] to replace the old air standard. It also represents their results of calculations of the ideal Otto-cycle efficiency in which the mixture has 25 per cent more air than is necessary for complete combustion, this being the mixture that usually gives the maximum thermal efficiency of an actual engine. According to their calculations the same result is obtained for this mixture regardless of whether dissociation is considered in the ideal cycle.

[7] See *The Automobile Engineer*, Feb., 1921, p. 58.

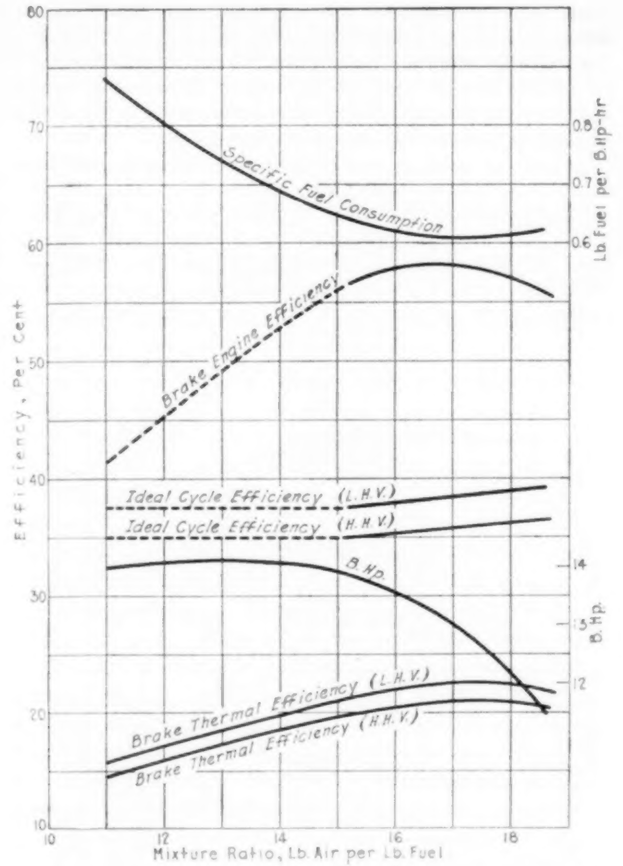


FIG. 10 85-PER CENT LOAD CURVES OF MARINE OTTO ENGINE

(Universal; 4 cylinders, $3^{1}/_{4}$ in. × $4^{1}/_{2}$ in.; compression ratio, 5; fuel, gasoline; speed, 1120 r.p.m. Data from student tests in Mechanical Laboratory, Cornell University.)

The results as given in Fig. 8 for the Diesel cannot be compared strictly with those of Goodenough and Baker because they used a different fuel. However, this would not account for nearly all the difference in the efficiencies, which amounts to about one per cent with 40 lb. of air per lb. of fuel, and becomes appreciably larger for the lower ratios of air to fuel, probably largely because the effect of dissociation is then so much greater. Possibly some of the difference is also due to the fact that they considered the fuel injected as a vapor instead of a liquid.

In this comparison it should also be pointed out that in this paper all results have been calculated on the assumption that the temperature of the mixture in the ideal engine at the beginning of compression is 200 deg. fahr., or in other words, $T_1 = 660$. It is realized that, strictly speaking, this temperature should be based on the compression ratio, the air-fuel ratio, and the temperature of the mixture entering the cylinder of the actual engine. All these factors make it difficult to select a suitable constant value of $T_1$ or to derive a logical equation for finding it. Goodenough and Baker have attempted the latter, and probably their value of $T_1$ is somewhat superior to the one used in this paper. However, from calculations made by the authors, it was found that a variation of 100 degrees in $T_1$ would cause a difference in the efficiency of only about 0.5 per cent, and this amount of variation in $T_1$ for the two sets of calculations was not approached in the Otto and exceeded slightly in the Diesel only at the very high compression ratios. Consequently it may be concluded that the selection of $T_1$ is not one of the most important factors in the calculations.

For actual engines operating with a deficiency of air there is involved the interesting technical question of what constitutes the mixture in the ideal engine on which to base the engine efficiency. Goodenough and Baker have considered the ideal engine for this case to use a mixture in which there is a deficiency of air, but at the same time the heat supplied is assumed to be that corresponding to complete combustion. This conception results in a low efficiency for the ideal engine and a correspondingly high value for the engine efficiency. On the other hand, the authors believe, for reasons given in the first part of this paper, that engines running under these conditions should be compared with an ideal that has sufficient air to support complete combustion. Here is an important technical point about which there may be considerable difference of opinion among engineers. This question does not come up for the Diesel because it seldom, if ever, operates with a deficiency of air.

Goodenough and Baker, also Tizard and Pye, gave no results based on the higher heating value and the authors of this paper would do likewise if they considered only their own preference. Even though the A.S.M.E. specifies in its present test codes that the higher heating value should be used in determining the thermal efficiencies of internal-combustion motors, such a procedure is not altogether logical, in the opinion of many members, and to the authors this question seems to be one worthy of further consideration by the Society.

### PERFORMANCE OF MODERN ENGINES

Probably most engineers in the past have not fully appreciated how important it is to determine the air-fuel ratio when making a thermal-economy test of an internal-combustion engine, or

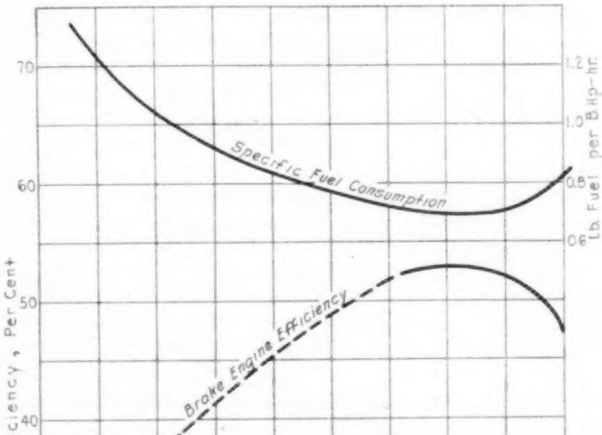


FIG. 11 FULL-LOAD CURVES OF AUTOMOBILE ENGINE

(Willys Knight; 4 cylinders, $4^{1}/_{8}$ in. × $4^{1}/_{2}$ in.; compression ratio, 4.4; fuel, gasoline; speed, 1000 r.p.m. Data from Bulletin 11, Purdue Engineering Experiment Station.)

perhaps in many instances the extra cost involved in making the more complete test has prevented it. In any case, in looking over the literature one has considerable difficulty in finding data including this important ratio.

The five sets of test results that are presented in graphical form in Figs. 10 to 14, inclusive, will serve to show the application of the ideal cycle efficiencies to determine the engine efficiencies under the various conditions as given. The test data were obtained from the sources indicated in the captions, and the engine efficiency has been calculated by using Equation [32].

In Figs. 10 and 11 are shown the performance curves of two small Otto engines running at constant speed, but with wide

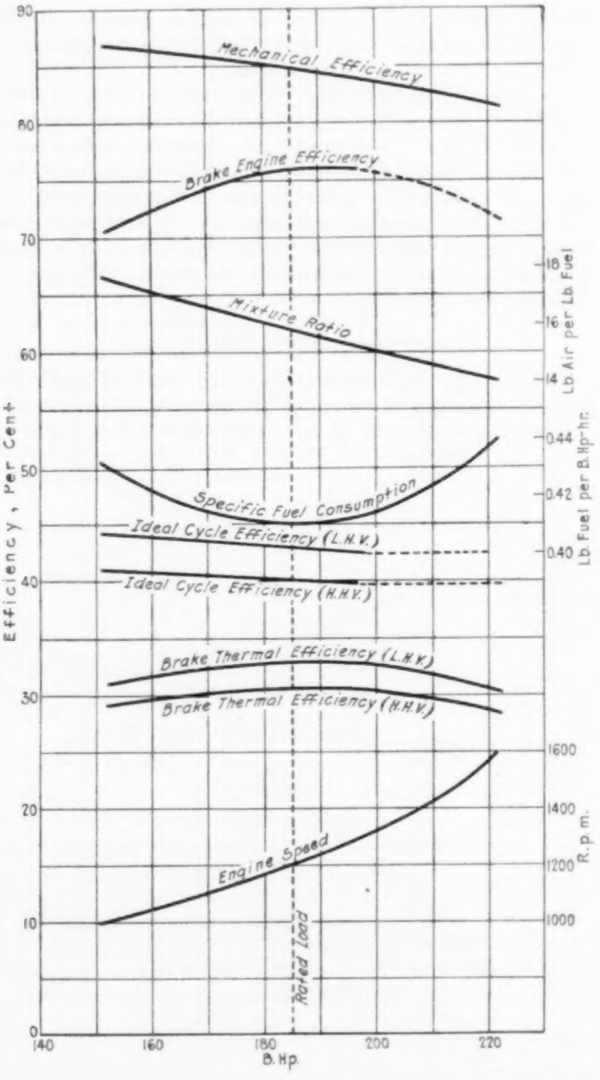


FIG. 12 PERFORMANCE CURVES OF 185-HP. AIRPLANE ENGINE
[Bavarian Motor Works; 6 cylinders, 5.90 in. × 7.09 in.; compression ratio, 6.7; fuel, gasoline. Test data from Report 135, United States National Advisory Committee for Aeronautics (1922).]

variations in air-fuel ratio, which are therefore plotted as abscissas. It is interesting to note from both of these figures how much more sensitive to a change in this mixture ratio are the engine and thermal efficiencies than is the power output. Thus in Fig. 10 the maximum power is seen to be 14.1 hp. for a mixture of 13 to 1, and the power is decreased only to 13 hp. for a mixture of 17 to 1, or this change in the air-fuel ratio causes a 7.8 per cent loss in power. At the same time the engine efficiency rises from 0.49 to its maximum value of 0.58, an increase of 18.4 per cent, and the brake thermal efficiency rises from 0.185 to 0.225, an increase of 21.6 per cent. The thermal and engine efficiencies do not increase in exactly the same proportion because the ideal cycle efficiency is not constant over this mixture range.

In both of these figures the curves representing the ideal

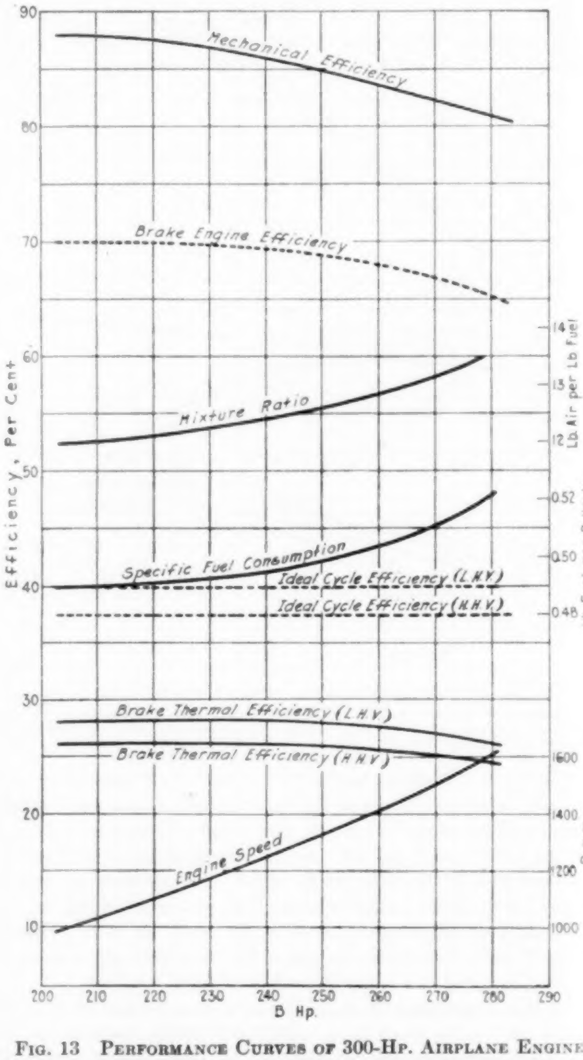


FIG. 13 PERFORMANCE CURVES OF 300-HP. AIRPLANE ENGINE
[Maybach; 6 cylinders, 6.5 in. × 7.09 in.; compression ratio, 5.9; fuel, 20 per cent benzol, 80 per cent gasoline. Test data from Report 134, United States National Advisory Committee for Aeronautics (1922).]

cycle efficiencies and the engine efficiencies are drawn with a broken line for those mixture ratios in which there is a deficiency of air, because it is desired to call special attention to this region concerning which there may be debatable ground as to the proper method of procedure.

The small marine engine whose performance curves are shown in Fig. 10 has given these same results on many different runs, as everything was under careful control. The motor could not be run at full load at this speed without serious detonation because it was cooled with steam at a temperature of 212 deg. fahr. This speed used was that which gave its maximum torque instead of maximum power.

In Fig. 12 and 13 are shown the results of tests of two airplane engines, operated with changes in both speed and mixture ratio.

Both of these tests were made in the altitude chamber of the U. S. Bureau of Standards, because full power was not supposed to be developed at sea level with these high compression ratios. Each one gives exceptionally high thermal and engine efficiencies, but this is especially true of the B.M.W. machine, whose maximum engine efficiency is, as may be seen from Fig. 12, slightly over 76 per cent.

In Fig. 14 are given the performance curves of a marine Diesel over its entire range of speed. These test data were obtained by the Marine-Oil-Engine Trials Committee of the Institution of Mechanical Engineers after very extensive tests. In their report they considered the ideal engine to have a constant efficiency of 52 per cent, whereas in Fig. 14 the variable

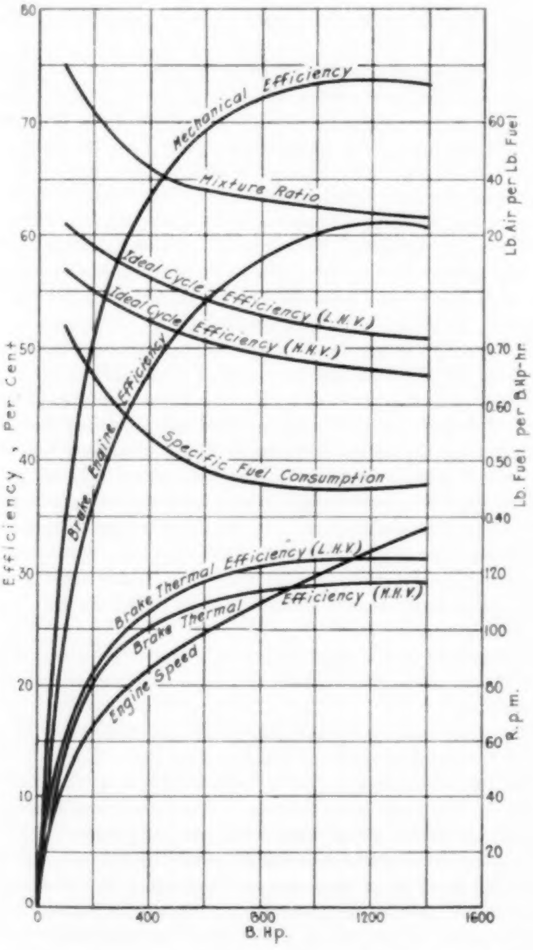


Fig. 14 Performance Curves of 1250-Hp. Marine Diesel Engine

(Richardsons-Beardmore-Tosi Director Valve; 6 cylinders, 4-cycle, 24.41 in. × 38.39 in.; compression ratio, 13; fuel, Anglo-Persian Diesel oil. Data from *Engineering*, vol. 118, p. 750.)

efficiencies of the real mixture standard are shown, and the corresponding curve for the engine efficiency was calculated by the authors as given in this figure.

Comparing the results of this marine Diesel test with those of the airplane Otto engine as given in Fig. 12, it is seen that the maximum thermal efficiency of this Otto engine is slightly better than the Diesel and the mechanical efficiency of the Otto is far superior. The combination of the lower mechanical efficiency and the higher cycle efficiency of the Diesel gives it an appreciably lower engine efficiency. Considerably better brake thermal efficiencies than those given in Fig. 14 are reported in *Engineering*[8] for both solid- and air-injection types of Diesels. These efficiencies are 34 and 36.7 per cent, respectively, for these two engines, but the air-fuel ratio and the compression ratio are not given, consequently the engine efficiency can not be determined.

## General Conclusions

The evidence presented in this paper and in those already published by other authors, indicates, to some extent at least, the difficulty and complexity of determining accurately the amount of energy available for the production of work in an internal-combustion motor. It also shows the necessity of making a few assumptions which may give rise to some difference of opinion among engineers. However, the final results obtained by different authors are for most cases in close agreement, and they all show very clearly that the "cold-air standard" with $\gamma = 1.4$ is too far from the truth to be further considered.

The results of the calculations of Goodenough and Baker, Tizard and Pye, and the authors are in close agreement except for those cases involving a deficiency of air, for which there is considerable divergence due to the different conceptions of what constitutes the mixture in the ideal engine and what is the proper method of treating dissociation in it. Considering the complexity of the problem, the final results obtained by different authors are, for most cases, in sufficiently close agreement to justify the hope that some of them, or a combination of them, may be accepted as standards by the A.S.M.E., or that at least they will serve to promote additional study and interest in the subject.

For the ideal Otto engine, in which no dissociation and no air deficiency are involved, the efficiencies calculated by the authors are given in Figs. 3, 4, and 5, for the fuels gasoline, benzol, and blast-furnace gas, respectively. For the Diesel using petroleum oil the results are shown by Fig. 8. The characteristics of these fuels were chosen to represent average values, and the results given in these curves may therefore be used for calculating actual engine efficiencies. In all of these curves the range of the compression ratio is more than sufficient for present practice. For all cases the ideal cycle efficiency is increased materially by a large air-fuel ratio and a high compression ratio, the fuel used being only of secondary importance. Thus for a compression ratio of 6 and just the right amount of air to afford complete combustion, the Otto gives efficiencies of 0.405, 0.398, and 0.397, on the lower heating values, for gasoline, benzol, and blast-furnace gas, respectively.

The efficiencies of the ideal engine are given for both the higher and lower heating values of the fuels because both are needed as standards at present. By using the same heating value for the ideal and actual, the engine efficiency will always be independent of individual preference in this matter. This advantage combined with the basic conception of the term, makes it one of the best measures of performance of an internal-combustion engine.


## Acknowledgments

Credit is due to Professors W. N. Barnard, G. B. Upton, and A. C. Davis, all of the Sibley School of Mechanical Engineering, for their many helpful suggestions and criticisms. Professor Davis also kindly furnished the test data on the Universal marine motor.

To C. O. Mackey, instructor in Sibley, and M. C. Tate, M.E., Cornell, 1927, grateful acknowledgment is made for their very able assistance in making the calculations and curves.


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[8] See p. 624, May 9, 1924.

## Discussion

Lionel S. Marks.[9] The writer is in entire agreement with the authors of this paper on the desirability of finding and standardizing some method of stating the engine efficiencies of internal-combustion engines. With steam engines and turbines the engine efficiency or, as we used to call it, the Rankine efficiency can be determined with no more uncertainty than is involved in the comparatively small errors in existing steam tables. With internal-combustion engines, however, there are several important uncertainties. In order to calculate the ideal efficiency, two things are necessary: (1) to define the cycle and (2) to know the physical properties of the working substance. In defining the cycle it is necessary to know the weight of the residual gases in the clearance space so as to be able to determine the weight and composition of the substance going through the cycle. Unfortunately, any exact knowledge of the weight of clearance gases is impossible without a knowledge of the mean temperature in the clearance at the beginning of the admission stroke. In the absence of such knowledge it is necessary to make some assumption, and the authors have assumed two temperatures, one at the beginning and one at the end of the admission stroke. Neither of these assumptions has any special validity. Other calculators in this field have made different assumptions. Second, with respect to the physical properties of the working substance, it is impossible to regard our present knowledge of specific heats at high temperatures as of great accuracy. Our knowledge of the chemical equilibrium of $CO_2$ and $H_2O$ in explosive mixtures at the maximum temperature is far from satisfactory. With these two uncertainties it is obvious that no accurate calculation of ideal cycle efficiency is possible.

Two other investigations have been made in this field in the recent past, and all three sets of investigators have had available the same experimental data for the determination of specific heats and dissociation. Comparing their results for a compression ratio of 5 with the Otto cycle, no excess air, and with benzine as fuel, their calculated efficiencies vary by 3 per cent in absolute efficiency or a variation of 9 per cent in comparative values. An engine which showed 70 per cent engine efficiency according to Ellenwood, would show 79 per cent efficiency according to Tizard and Pye. And this is not all. Further investigations on specific heats and dissociation may quite easily yield new values of these quantities which may change engine efficiencies as calculated by these three sets of investigators by 3 or 6 per cent. In other words, the engine efficiencies calculated from the cycle efficiencies given in this paper may quite easily be from 10 to 15 per cent wrong.

Under these circumstances it does not seem to the writer that the time is ripe for the official adoption by the A.S.M.E. of any such set of ideal efficiencies as those calculated in the paper. It will always be desirable for those engaged in research in this field to calculate engine efficiencies, but it should always be on the basis of the best information available at the time.

An argument might, the writer thinks, be made for the use of an air-cycle standard which is different both from the cold-air cycle which has been adopted generally up to the present time and also from the hot-air standard as defined in this paper. The specific heat of air at high temperatures is known more accurately than the specific heats of $CO_2$ and $H_2O$, and there is no dissociation when air only is present. In place of using the cold-air standard which has been in general use and which has no justification other than the simplicity of the calculations involved, an air standard might be adopted which would take into account the change of specific heat of air with temperature. This is something quite different from the hot-air standard of the paper. It would be an arbitrary standard that would have the advantage of being nearer to the true ideal efficiencies than the customary air cycle and would actually give correct values for Diesel engines at the lower limit of power, that is, with no fuel injected. For Otto cycles it could not be approached closely because of the non-explosibility of mixtures with a large excess of air.

G. A. Goodenough.[10] This paper is a welcome contribution. If the "air standard" as a measure of efficiency is to be discarded, as it undoubtedly should be, a body of data on the ideal thermal efficiencies of internal-combustion motors must be provided. The paper gives results that supplement the data which have already been furnished by Tizard and Pye, and by Goodenough and Baker.

The subject of engine efficiency is admirably covered. All that is said in this connection may be endorsed without reservation. It seems, however, that the authors have introduced a contradiction in their assumption as to the efficiency of an engine operating with a deficiency of air. As stated, the engine efficiency should indicate the success of the designer and builder in reducing the various losses inherent in the engine. Deficiency of air results in a loss of efficiency; but this loss should be charged to the operator, not to the engine. In other words, it seems only fair that the effect of insufficient air should be reflected in the thermal efficiency rather than in the engine efficiency.

It is gratifying to note that the authors have an opinion relative to the use of the high and low heats of combustion. They point out that only the low value can enter into Equation [17]; likewise with Equation [29]. In the calculations that involve dissociation the heats of combustion of CO and $H_2$ are also used, and these must invariably be the low values. In no phase of the analysis of a cycle can the higher heat of combustion possibly enter into the calculation. It is only in the final step, the determination of the efficiency, that the high value functions. By an arbitrary edict of the power test codes committee, the high value here usurps the place that rightfully and logically belongs to the low value.

It might be well if the terms "high" and "low" were replaced by "gross" and "net," which are used by some of the English authorities.

The discrepancies between the tabulated efficiencies and those given by Goodenough and Baker are noted. They are due, of course, to the different systems of analysis and to slight differences in the basic assumptions. The Goodenough and Baker analysis took account of dissociation, and as a result the efficiency values are somewhat lower under certain conditions. But leaving out the effect of dissociation, there remains a small discrepancy that needs explanation. A close examination of the results given in Tables 3 and 8 of the paper discloses two reasons why the E. E. and C. values should be higher than the Goodenough and Baker values. These are: (1) the amount of residual gas carried in the charge; and (2) the interpretation of L.H.V. in Equations [17] and [29].

The authors say that the residual gas cannot be calculated accurately, hence they make the convenient assumption that this gas fills one-half the clearance volume under certain conditions. With this assumption they find in case 11 the weight of residual to be 1.96 lb. per lb. of fuel. In the same case Goodenough and Baker find 0.535 lb., or less than one-third as much. Perhaps an accurate calculation is not possible, but even a rough estimate favors the smaller figure.

In Table 3, case 11, the gas constant of the fuel mixture is

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given as 51.57, and a rough calculation shows that the constant for the mixture of products is about 54. Taking 51.6 and 54, and the values of $T_3$ and $T_4$ given in Table 3, the pressure at point 4 is found to be

$$p_4 = 14.7 \times \frac{54}{51.6} \times \frac{3521}{660} = 82.3 \text{ lb. per sq. in.}$$

In the first phase of the exhaust the pressure drops from 82.3 lb. to 14.7 lb. simply because the greater part of the cylinder contents has passed out. The temperature of the part going out is somewhat reduced on account of throttling, but this reduction does not extend to the part remaining in the cylinder, which, under the ideal conditions assumed, remains practically at a temperature of 3521 deg. The slight drop in temperature due to work of expansion is negligible. The fraction that remains in the cylinder is therefore 14.7/82.3. In the second phase of the exhaust, the piston pushes out of the cylinder $^4/_5$ of this amount. The total amount of charge (per pound of fuel) at point 3 is $1 + 15.2 + M = 16.2 + M$, where $M$ denotes the weight of the residual. There remains in the cylinder at the end of the exhaust stroke

$$\frac{1}{5} \times \frac{14.7}{82.3}\left(16.2 + M\right) = 0.0357\ (16.2 + M)$$

Hence $$M = 0.0357\ (16.2 + M)$$

or $$M = 0.604 \text{ lb.}$$

This result is for $T_1 = 660$; Goodenough and Baker obtain $M = 0.535$ with $T_1 = 638$.

Has the amount of residual any effect on the efficiency? To answer this question, the efficiency for this case was recalculated: (1) with the residual found by Goodenough and Baker; (2) with the residual given by Table 3. Dissociation was neglected in both cases. The results, along with those already given, are as follows:

| | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Efficiency, per cent |
|---|---|---|---|---|---|
| E. E. and C. | 660 | 1124 | 5116 | 3521 | 37.38 |
| Residual 0.54 lb., no dissociation | 638 | 1081 | 5363 | 3740 | 37.18 |
| Residual 1.96 lb., no dissociation | 638 | 1081 | 5106 | 3516 | 37.60 |
| G. and B., with dissociation | 638 | 1081 | 5053 | 3736 | 35.97 |

The efficiency is thus increased about 0.4 per cent by taking the increased residual.

It may be conceded that the assumption of E. E. and C. agrees fairly well with the conditions in the actual engine. But it appears hardly logical to assume ideal conditions for three of the phases of the cycle and then abandon the ideal for the real in the fourth phase.

A second reason for the discrepancy lies in a difference of the interpretation of the combustion process 2–3 in the two cycles; this process involves the heat of combustion of the fuels. Let the authors' L.H.V. be denoted simply by $L$; then $L_v$ denotes heat of combustion at constant volume, and $L_p$ that at constant pressure. By the definition of heat of combustion,

$L_v$ = total internal energy of factors — total internal energy of products.

$L_p$ = total enthalpy of factors — total enthalpy of products.

The restriction is imposed that the final temperature of the products shall be the same as the initial temperature of the factors. The fuel factor may be taken as 1 lb.; then $L_v$ and $L_p$ are heats of combustion per pound. From the preceding definitions, $L_v$ and $L_p$ depend upon the temperature at which the process is conducted; the $L_v$ for $T = 1500$ may be, and generally is, quite different from the $L_v$ for $T = 500$.

The total internal energy of a gas mixture (denoted by $I'$) is

$$I' = I_0 + I$$

in which $I$ denotes the thermal energy as given by Equation [10], and $I_0$ denotes the energy the mixture would have at absolute zero; in reality the chemical energy. Consider now the process 2–3 of the Otto cycle. No work is done, and the process is assumed to be adiabatic; hence

$$I'_2 = I'_3$$

Let subscripts $m$ and $p$ be used to denote the initial and products mixture, respectively; and subscripts 2 and 3 to denote states 2 and 3. Then the preceding equation becomes

$$I_{0m} + I_{2m} = I_{0p} + I_{3p}$$

The difference $I_{0m} - I_{0p} = L_0$, the heat of combustion at absolute zero; hence

$$I_{3p} = I_{2m} + L_0$$

or in the notation of Equation [17],

$$i_3 = i_2 + w_f L_0$$

If the authors had used this formula, they would have been saved the calculation of the $i'_2$ values. However, taking Equation [17], what particular value of L.H.V. is implied? The equation

$$I'_{2m} = I'_{3p}$$

may be changed to

$$I'_{2m} - I'_{2p} = I'_{3p} - I'_{2p} = I_{3p} - I_{2p}$$

The first member is $L_{v2}$, the heat of combustion at temperature $T_2$, and the second member is the difference which was used in Equation [17]. Hence the L.H.V. in Equation [17] should properly be the heat of combustion at temperature $T_2$, and this will vary with $T_2$. From an examination of Table 3, it appears that the authors have used throughout the constant value $L_v = 18{,}830$. The effect, however, is almost negligible except at the highest values of $T_2$. For example, in case 18 the value of $I_3$ becomes 1119.0 instead of 1117.2.

The Diesel cycle presents a different picture. The relations are somewhat more complicated because the fuel and compressed charge are kept separated up to the state 2. Let the subscript $a$ refer to the mixture of air and residual gas that is compressed from state 1 to state 2. The energy equation for the adiabatic process 2–3 is (taking 1 lb. of oil)

Work $_{2-3}$ = energy of gas $a$ in state 2 + energy of oil—energy of products in state 3

or

$$Ap\,(V_3 - V_2) = I_{oa} + I_{a2} + i_{o(\text{oil})} + i_{(\text{oil})} - I_{op} - I_{p3}$$

If the work of injection is included, the effect is to change $i_{(\text{oil})}$ to $h_{(\text{oil})}$. But

$$I_{a2} + ApV_2 = H_{a2} \qquad I_{p3} + A_{p3}V_3 = H_{p3}$$

and $$I_{oa} + i_{o(\text{oil})} - I_{op} = L_0$$

The equation becomes, therefore,

$$L_o + h_{(\text{oil})} + H_{a2} = H_{p3}$$

Here, again, a constant is added to $H_2$, the enthalpy of the initial mixture, *not* to the enthalpy of the products mixture. The calculation of $h'_2$ is quite superfluous. The symbol $h_{(\text{oil})}$ stands for the enthalpy of the oil at the temperature it has when injected.

Not knowing the characteristics of petroleum oil, we assume that they follow somewhat closely those of kerosene.

For the latter fuel, Goodenough and Felbeck's figures show that the sum $L_0 + h_{(oil)}$ is about 1.2 per cent greater than the value of $L_p$ at ordinary temperature. Hence, we assume for petroleum oil $L_0 + h_{(oil)} = 18{,}250 \times 1.012 = 18{,}470$ B.t.u. per lb.

With this value of the constant, and with other data from Table 8, the following results are obtained.

| Case No........ | | 45 | 52 | 57 | 61 | 65 |
|---|---|---|---|---|---|---|
| $h_3$ (revised) | = | 1244.3 | 860.1 | 737.2 | 682.5 | 650.3 |
| $h_3$ (Table 8) | = | 1276.3 | 877.2 | 749.1 | 690.4 | 657.5 |
| Difference, per cent | | 2.6 | 2.0 | 1.6 | 1.15 | 1.1 |

The effect, of course, of a larger value of $h_3$ is a higher temperature $T_3$ and larger volume $V_3$. The area of the ideal indicator diagram is thereby increased, and with it the efficiency.

Taking no account of dissociation, it appears that the E. E. and C. values for ideal efficiency will be higher than the Goodenough and Baker values for both Otto and Diesel cycles. In the case of the Otto cycles, the reason lies chiefly in the difference between the amount of residual gas assumed. In the case of the Diesel cycle this factor has slight effect and the discrepancy lies chiefly in the difference between the two interpretations of the combustion process 2–3.

The effect of dissociation is easily explained. Referring to Table 2 of Bulletin No. 160, case No. 9 shows at the point 4, $x_4 = 0.9756$, $y_4 = 0.995$. This means that unburned CO and $H_2$ are present in the exhaust. From the data on p. 34 of the bulletin it is found that the chemical energy thus thrown away is 1.3 per cent of the chemical energy of the gasoline. From the calculation previously shown, $T_4$ with dissociation is 3736 deg. and without dissociation is 3740 deg. The thermal energy $I_4$ is nearly the same in the two cases. If it were exactly the same, the difference in efficiency would be precisely 1.31 per cent. Actually it is 1.21 per cent. The decrease of efficiency due to dissociation becomes significant when the end temperature $T_4$ is higher than 3300 or 3400 so that an appreciable amount of unburned gas is thrown into the exhaust. With 100 per cent or more air, $T_4$ will be high (1) when the air supply is a minimum, and (2) when the volume ratio $r$ is small. Inspection of Fig. 9 shows that these are the conditions that give the greatest discrepancies between the two sets of curves.

John B. Baker.[11] The objection to the air standard is that it is a standard impossible to attain. In establishing a new standard we must make sure that our standard is not working a hardship on the engine being compared. It would appear that assumption $e$ of the authors imposes a condition which has no physical significance. Why should we compare an engine which is running on an air deficiency with an ideal which specifies the theoretical amount of air necessary for complete combustion? If we are comparing an engine with deficient air to such a standard there seems to be no justification for changing our standard when an excess of air is used. If a steam engine is supplied with steam with a quality of 95 per cent we do not charge the engine with the heat which the steam might have had had it been saturated.

In the publication of Goodenough and Baker on the same subject the method of analysis was extended to the case of insufficient air. This analysis considers the dissociation of the products of combustion. It is true that with a large excess of air the maximum temperatures reached are lower and the consequent dissociation is negligible. With less air, however, this phenomenon of dissociation becomes the dominating factor. With insufficient air for complete combustion we can conceive of the dissociation of the primary products of combustion until equilibrium is attained between CO, $CO_2$, $H_2$, and $H_2O$. It may be true that the primary products are not $CO_2$ and $H_2O$, but at any rate the equilibrium is attained.

In this analysis the heat of combustion for the complete combustion of the fuel enters, but a considerable portion of this heat is used to form the large quantities of CO and $H_2$ present. This appears in Equation [21] of the reference quoted. The actual heat supplied is not then the heat value for complete combustion as inferred in the present paper.

E. A. Allcut.[12] A number of attempts have been made to establish a standard cycle for the internal-combustion engine to occupy a position similar to that held for many years by the Rankine cycle in steam-engine practice. The old "air cycle" is defective as an ideal because it neither takes into account variations in specific heat, which become serious at high temperatures, nor changes in the composition of the working fluid which take place during the cycle. With so many variable factors many tables must necessarily be prepared, as in the present paper, and the labor involved in computing them is great. Such labor, moreover, is wasted to some extent, unless the tables and curves come into reasonably general use, and it would seem that the present state of knowledge in this subject is sufficiently accurate to permit the compilation of a series of tables and curves similar to the steam tables, so that efficiency ratios of engines of different types may readily be compared. For that work the present paper might well serve as a basis. Professor Marks has deprecated that suggestion, and the writer is sorry to be unable to agree with him for the reason that had we waited until we reached the present state of knowledge in the preparation of steam tables, we should not have made anything like the amount of progress in steam engineering that we actually have made.

The writer is in general agreement with the methods of calculation employed, but before any authoritative tables or curves can be drawn up as standards it will be necessary to consider very carefully what factors shall be included in the standard efficiency and what characterized as unavoidable losses. For instance, the writer wishes most emphatically to dissent from the general attitude of the authors on calorific values and particularly to certain statements, one of which is as follows: "This available energy, as previously explained, can never be based logically on anything but the lower heating value for the internal-combustion motor." (Page 7.) This seems to be a decidedly retrograde step, particularly in view of the fact that the most recent test codes used in America, England, France, and Germany have all expressed in no uncertain terms the desirability of using the higher heating value as a basis for all efficiencies. The word "logical" in this connection was particularly ill chosen, as anything less logical than the lower heating value could hardly be conceived. If it be maintained, as it has been, that no internal-combustion engine can reject its heat at temperatures lower than 212 deg. fahr., why fix on this as a standard? The argument applies equally well to 300 or 400 deg. fahr. Even if 212 deg. be arbitrarily selected (and there is nothing logical about that) there is still the heat of the liquid and the sensible heat of the gases below 212 deg. which are still included as losses, although they come within exactly the same category as the latent heat which is not so included, if the lower calorific value be used. Consider the case of the combination of a gas producer and gas engine. Is the gas maker to be penalized because the engine, which he does not design, and over which he has no

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control, is unable to use all the heat in the fuel supplied? The higher value is used with solid fuels, why not with liquid? A further practical point is that many liquid-fuel calorimeters give the higher value alone and the lower can only be obtained by calculation from the analysis, which few engineers are able to perform and which is not always available from other sources.

If it be argued that the latent-heat loss is inevitable and is the most important factor in the exhaust loss, the same argument could be used for omitting the frictional loss in the engine, or a portion of it, as this is equally inevitable and just as important. By excluding these and a few other necessary losses, efficiency ratios of 100 per cent might be realized and the designer could then sit back complacently.

It follows from this that both on logical and practical grounds the case for the use of the higher value is overwhelming, and the writer deprecates any attempt to revert to the lower value as a basis.

These and other similar points must be thrashed out thoroughly before any cycle or method of calculation can be established, but there is no reason why a committee should not be appointed to consider these factors and draw up a report indicating the best method of procedure in this connection.

L. C. Lichty.[13] There have been four noteworthy steps made in the development of an analysis of the internal-combustion-engine cycle:

1 The air-standard cycle
2 The use of variable specific heats
3 The use of the actual mixture with the above
4 The inclusion of chemical equilibrium in the combustion and also the expansion process.

The object of an analysis is to determine the maximum possible efficiency of the ideal cycle and to use this as a goal which one should strive to approach. The difference between the indicated thermal efficiency of an actual engine and the maximum thermal efficiency of an ideal engine under the same conditions is a measure of the possibility for improvement. The use of the air-standard cycle is, or should be, obsolete as a basis for comparison, for it represents much more than the maximum efficiency that might be obtained in the ideal cycle. An analysis which does not include the last three of the items mentioned above gives a result that can never be attained even in the ideal case.

A well-designed internal-combustion engine with a 5-to-1 compression ratio using gasoline as a fuel will have an indicated thermal efficiency of about 30 per cent. With the analysis under discussion, the maximum attainable with 100 per cent air is 37.5 per cent, while considering chemical equilibrium,[14] the maximum is 35.9. Instead of a possible improvement of 30 to 37.5 per cent, only 79 per cent of this improvement is possible, 21 per cent of the difference being explained by a consideration of equilibrium conditions. An item which is an inherent characteristic of the medium, which will explain one-fifth of the difference between actual and ideal efficiencies, is of considerable importance and should not be disregarded.

The air-standard cycle with constant specific heat has been superseded by the variable-specific-heat cycle; it in turn has been improved by a consideration of the actual medium being used. With the application of the present knowledge of chemical equilibrium the efficiency of the ideal internal-combustion-engine cycle has been determined more closely than ever before. The use of this item in the determination of the ideal efficiency is a distinct step in advance and gives one a true idea of the maximum possible efficiency attainable.

The work of Goodenough and Baker[14] takes into account all of the data available regarding the behavior of the medium used in an internal-combustion engine and furnishes us with a true guide with which to compare actual performance. Engine efficiencies determined by comparison with Goodenough and Baker's efficiencies represent true performance factors. Engine efficiencies determined from other than such analysis represent fictitious values which discredit the engine performance, in the light of present knowledge on this subject.

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C. N. Cross.[15] The authors of this paper should be congratulated for having presented to the engineering profession a contribution which advances one more stage the detailed information concerning internal-combustion-engine performance. This paper presents a very ingenious method of attack of the problem and it represents a vast amount of laborious detail which speaks loudly of the authors' patience and perseverance.

However, it is the opinion of the writer that the authors err to some extent when they, after having expended so much effort to arrive at an exact series of results which they urge shall be adopted as a standard by the Society, omit an important variable. Nowhere in their extended development has any provision been made for the variations of the specific heat at constant pressure for changing pressure. The effect of this variation is by no means negligible and as yet its full extent at high temperatures and high pressures is only partially determined for air,[16] and so far as the writer is aware, is entirely unknown for the other gases involved.

If the authors wish to be utterly accurate and complete in their proposed standards for the efficiency of internal-combustion engines, it would seem to the writer that Equations [8] and [9] should include terms which allow for the changes due to pressure. Until such time as that is possible, the "Air-Standard Efficiency," proposed in 1905 by a committee of the Institution of Civil Engineers of Great Britain appointed to study the standards of efficiency of internal-combustion engines, should remain as the standard of performance. The Committee stated that—

> "......Apart from the special difficulty that knowledge of the values of $c_p$, $c_v$, and $k$ at high temperatures [the writer adds *and high pressures*] is defective, the calculation of their values for each special mixture of gases used in internal-combustion engines is cumbrous, and in ordinary trials almost impracticable. There is further difficulty that the values are not quite the same for compression and expansion strokes. In the opinion of the committee, it would introduce some uncertainty and difficulty, without adequate compensating advantage, to make the standard engine cycle depend on a knowledge of the physical constants of the mixture used. The discussion of the constants for various mixtures of gases already given shows that, apart from the unknown change at high temperatures, these constants do not differ by more than 2 per cent to 5 per cent from those of air in such mixtures as are used in gas engines. The advantages of simplicity and definiteness in the standard are so great that the committee recommends that the standard engine should be taken to work with a perfect gas of the same density as air. This in no way prevents any one from discussing the distribution of heat losses in any particular mixture of gases. But it does render more definite the statement of relative efficiency, without, in the opinion of the committee, introducing any error of practical importance."

It is the opinion of the writer that the above-quoted statement of the committee is still substantially valid. And further,

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[16] See M. Jakob, "Specific Heats of Air for Ranges of Temperature from —80° C. to 250° C. and for Pressures from 0 to 200 × 10[4] Kg. per Sq. Metre," in *Science Abstracts*, A, Physics, vol. 27 (1924), p. 194. The original appeared in *Zeit. Tech. Physik.*, vol. 4 (1923), No. 12, pp. 460–468.

that it would be inadvisable, in the light of our present incomplete knowledge of the values of the various physical constants of gases under all the varying conditions existing in the cylinders of internal-combustion engines, to adopt, or even urge for general adoption, any new standard of ideal efficiency at the present time.

G. B. Upton.[17] It is said that the revolutionary advances in recent years in knowledge of the nature of matter are due primarily to an increase in the accuracy of measurement of fundamental constants. Engineering is working out today advances paralleling those of physics and chemistry. Such a change to more accurate fundamental standards is the calculation of the "real-mixture" standards for internal-combustion engines; without such "real-mixture" standards we cannot make intelligent headway in improvement of the utilization of heat in the engines.

Knowledge of the specific heats of gases at high temperatures is still undergoing change, but those changes promise henceforth to be of little importance. The time is ripe for definition of the "real-mixture" ideal cycles for internal-combustion engines and calculations of ideal efficiencies based upon the real properties of the actual working substances. In this definition no one, the writer thinks, will disagree with the paper as to conditions (*a*), (*b*), (*c*), and (*d*); but the case is otherwise with conditions (*e*) and (*f*).

In the first part of condition (*e*), which is a double-header, the authors decide that when an engine is operated on any mixture richer in fuel than the "theoretical mix," the theoretical cyclic efficiency charged against the engine shall be that calculated for the theoretical mix. This penalizes the "engine efficiency" for the use of a rich mix, which may be a good way to educate the operator of the engine. On the other hand, the operator may know something which is not in the thermodynamic analysis, that at full power of the engine a lean mix will give a very hot and oxidizing exhaust which will burn out the exhaust valves. If the engine efficiency is to be measured fairly for all mixes rich or lean, then the penalization for use of rich mixes should fall upon the cyclic efficiency. The discusser has done this roughly by multiplying the cyclic efficiency for the theoretical mix by the mix ratio of the rich mix and dividing by the mix ratio of the theoretical mix; but this is an over-correction, because the rich mixes from their content in their products of combustion of CO and $H_2$ get an effect like that from $N_2$ and $O_2$ in the lean mixes—the ratio of specific heats for either rich or lean mixes is higher than that for the theoretical mix. Also, for many of our liquid fuels the increase in "gas constant" by combustion (or number of molecules present) is greater for rich than for lean mixes. Decision as to how the rich mixtures are to be treated is obviously a matter of arbitrary choice, with plausible arguments on either side.

The second part of condition (*e*) concerns the weight of residual exhaust gases entrapped with the new charge at the beginning of the compression stroke. A few years ago we did not consider these exhaust gases at all; our "working substance" in the "perfect-gas" style of thermodynamic theory was magically cooled at constant volume from the temperature at the end of the expansion line to the temperature at the beginning of the compression line, so that the cycle could begin anew. Now that we recognize the expulsion of used charge and taking in of new charge as parts of the real cycle, we need to know how much residual exhaust gas carries over from each cycle to mix with the new charge of the next cycle. The authors say that this quantity cannot be calculated accurately, but use an arbitrary assumption which may be fairly accurate, that it would fill one-half the clearance volume when reduced to the pressure and temperature assumed at the beginning of compression. Since the exhaust and intake pressure losses of the ideal cycle have already been assumed as zero in condition (*b*), both residual exhaust gas and new charge have atmospheric absolute pressure; the temperature of the total charge at beginning of compression is assumed in condition (*c*) as 200 deg. fahr., or 660 deg. fahr. absolute. Hence the authors have really assumed that the clearance volume full of residual exhaust gas, at the end of the exhaust stroke, had a temperature of 2 × 660 deg. fahr. absolute = 1320 deg. fahr. absolute = 860 deg. fahr. under all conditions of mix and compression ratios. Goodenough and Baker, in their University of Illinois Bulletin No. 160, for this same calculation make two successive assumptions. First, between the end of expansion and beginning of the exhaust stroke, an *isothermal* process reduces the quantity of gases in the cylinder in the ratio of atmospheric pressure to absolute pressure at end of the expansion line. Second, the exhaust stroke (of a four-stroke cycle, obviously) pushes out gas at constant (atmospheric) pressure, making a further quantity reduction in the ratio of clearance/(displacement + clearance); with retained gases filling the clearance still at the temperature of the end of the expansion line — 3000 or more degrees fahrenheit absolute. No wonder that the authors and Goodenough and Baker disagree as to the weight of clearance gases retained.

If we are setting up a "real-mixture" standard, why not calculate according to what the engine does and must do with the exhaust? When the exhaust valve opens, hot gases of an absolute pressure more than twice atmospheric are offered a passage like a nozzle through which to escape. They expand adiabatically, passing the valve with a velocity approximating that of sound in the hot gases until the cylinder pressure goes under twice atmospheric. In this period from 50 to 70 per cent of the exhaust gas escapes from the cylinder. Then the pressure still falls in the cylinder, with continuing adiabatic conversion of heat energy into velocity energy of escaping exhaust, velocities decreasing as the pressure runs down, until the cylinder pressure reduces to atmospheric. The resulting temperature in the cylinder is directly calculable from the pressure change and the adiabatic nature of the expansion as the exhaust gases blow themselves out of the cylinder. Then follows the exhaust stroke of the engine, if it is a four-stroke-cycle engine, expelling further exhaust gas till the volume is reduced to clearance volume, the temperature of the retained gas remaining, in a non-heat-conducting cylinder, the same as at the beginning of the exhaust stroke. Figured according to this adiabatic-expansion scheme the temperature of the exhaust gas trapped in the engine clearance is roughly 70 per cent of the absolute temperature at the end of expansion. Correspondingly, the volume occupied by this residual gas, when cooled to 660 deg. fahr. absolute, will be 0.27 to 0.30 times the clearance volume. In a real engine with "radiation" losses of heat to the jacket water the temperature at the end of expansion is appreciably lower than in the ideal engine and the residual exhaust gas is denser, amounting on account of this temperature item alone to 35 per cent or more of clearance volume when reduced to 660 deg. fahr. absolute temperature.

When the other effects in the real engine, of exhaust back pressure and intake suction, and heating of new charge on its way into the cylinder are taken into account, the arbitrary assignment of 50 per cent of clearance volume, at 660 deg. fahr. absolute, becomes a very fair statement of the real case. Whether this 50 per cent of clearance, as measuring full-load dilution of new charge with exhaust gas, is properly taken over from the

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real engine into the ideal cycle by the authors, may be a matter of argument; but the corresponding calculation of Goodenough and Baker cannot be justified on any grounds whatever. Actual dilution must vary with mix ratio more than with compression ratio, but cannot be constant even in the ideal engine. We must choose between two cases: either we compute the residual charge for the ideal engine to get the exhaust-gas dilution for the working substances of the ideal engine, making that working substance different from that of the real engine; or we assume for the ideal engine the same dilution as the real engine with all its imperfections, thus making the working substance of the ideal engine exactly identical with that of the real engine.

Condition (*f*) of the paper is that dissociation is not to be considered. Dissociation is variable with temperature, and persists even to the end of expansion if temperatures are high enough. Practically, the temperatures are too low for dissociation effects at the end of expansion in actual engines, but not always so in ideal cycles. Dissociation acts in the same way as the fact that combustion requires time and does not really occur at constant volume. Portions of charge that burn before or after the inner-dead-center position of the pistons have lesser expansion ratios than if all the burn happened at the dead center, and have correspondingly lessened efficiencies. Dissociation holds off a part of the combustion which should happen at dead-center position, and lets it occur later on during the expansion stroke, at reduced expansion ratio. On the other hand, dissociation increases the gas constant of the products mixture, which helps to increase expansion work. It is dubious whether it pays to go through with dissociation calculations, because in the real engine the temperatures throughout the burned charge are not uniform but far from it so that we have no satisfactory basis on which to make calculations. This non-uniformity of temperature in the burnt charge means, however, that dissociation is greater in the real engine, for a given average temperature of gases, than in the ideal engine. The real engine runs enough colder than the ideal one so that dissociation is not likely to be appreciable except perhaps at peak of combustion. The discusser feels that dissociation is still too uncertain a topic for us to try to put its effects quantitatively into our calculations of standards. Because Goodenough and Baker assumed too small a value for dilution with spent gas, their whole expansion line is pitched at too high a temperature. This not only makes their efficiencies everywhere a bit too low, but especially vitiates seriously their numerical estimates of the importance of dissociation. Their too small dilution makes their expansion-line temperatures come out 250 to 200 deg. fahr. too high. Such a temperature difference may easily change the completeness of combustion from 95 per cent back to 85 per cent, vastly overvaluing therefore the dissociation and its effect on efficiencies.

Concerning the use of "lower" and "higher" heating values of fuels, admittedly we must use "lower" values for computing temperature rises in the ideal cycle and must even recognize that the "lower" value is a function of the temperature at beginning of combustion. But in computing our thermal efficiencies we are comparing our heat engines with a device for perfect recovery of heat from combustion of the fuel, such as the counterflow gas calorimeters are. The perfect heat machine recovers the "higher" heating value. If we choose to operate a heat engine on a cycle which makes us throw away exhaust heat, it is entirely proper that the cyclic efficiency should be lower in consequence of that choice. The fact that the calculation of details (separate processes) of the cycle makes the computer use the lower and not the higher heat value of the fuel (because in the combustion process $H_2O$ is always vapor) should not warp his judgment as to how the cycle compares with a perfect heat utilization. It is physically possible to build a steam boiler in the form of a Junker gas calorimeter and get 100 per cent boiler efficiency with natural draft and yet with discharge gases reduced to atmospheric temperature; we do not build boilers that way because the interest on the plant cost would exceed the saving on fuel. Similar practical considerations lead us to use the Otto and Diesel cycles for internal-combustion engines, letting the exhaust go out too hot for $H_2O$ to be possibly condensed; the consequent heat loss as compared with a calorimeter is properly chargeable against the cycle of operation.

P. H. Schweitzer.[18] We have heard conflicting opinions on many factors with regard to establishing efficiency standards for internal-combustion engines. Higher and lower heating value, dissociation and no dissociation, admitting deficiency of air in the ideal cycle or excluding it, complete scavenging or residual gases. The writer has no desire to enter into any of these controversies, but instead of that would add one more. All recent efficiency calculations like those of Goodenough and Baker, of David, and of the authors are based separately on the Otto cycle and on the Diesel cycle. It might not be out of place to call attention to the proposal made by Professor Langer, who suggests abolishing the Diesel cycle altogether as an ideal reference cycle and basing the efficiency values on the Otto cycle solely, even if compression-ignition engines are being considered.

The writer will not attempt to reproduce Langer's argument which was presented at the 1927 meeting of the Society of German Engineers and is printed in the June 25 issue of the *Zeitschrift des Vereines deutscher Ingenieure*, but will mention a few good points in its favor. Constant-pressure combustion was formerly considered desirable because it gave lowest maximum pressures. Being desirable it was set up as an ideal standard. From the standpoint of efficiency the cycle with constant-pressure combustion is not ideal at all and is decidedly inferior to the cycle which admits all or most of the heat at dead center. The more our skill in machine construction improves the less we fear high pressures, and today very few builders of Diesel engines attempt to imitate the true Diesel cycle, which sacrifices efficiency to lower the pressure peaks. High-grade Diesel engines of today burn the greater portion of the fuel at or near dead center. That means a pressure rise during combustion, but it results in higher m.e.p.'s, lower exhaust temperatures, and better economy.

Taking the constant-pressure cycle as a reference, it is possible that some day we shall find that an actual Diesel engine has a thermal efficiency higher than ideal, simply because it burns the fuel quicker than corresponds to constant pressure. The engine efficiency would then be better than 100 per cent. This is absurd. If we do not want to add undesirable complications by introducing the dual cycles as ideal reference cycles, it is logical to accept the proposal of Professor Langer and compare all internal-combustion engines with the Otto cycle, which admits all of the heat at dead center and which really represents the limit which can be reached in efficiency with engines of the present general design.

Edgar J. Kates.[19] This paper presents calculations of great help to the busy engineer who wishes to measure the performance of an Otto or Diesel engine. The "air-standard" efficiency formerly in voge is now known to be so much in excess of the efficiency based on real gases and on real specific heats that it

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is of little practical value. On the other hand, the calculation of the ideal efficiency, taking into account the actual constituents of the mixture and the variations in specific heat, is so laborious a task for most engineers that they have denied themselves the benefits of this method of checking the performance of the engines with which they were concerned. This difficulty the authors have gone far to eliminate through the exceedingly simple and practical form into which they have condensed the results of many intricate computations. With the help of the charts given in this paper, the process of finding the ideal efficiency is reduced simply to locating a single point on a curve.

Though the charts cover a wide range of conditions for the Otto and Diesel cycles, they unfortunately do not apply to one of the most modern types of oil engines that operating on the "dual cycle," which is a combination of both the Otto and the Diesel. In the dual cycle, part of the fuel is burned under constant-volume conditions at dead center, as in the Otto, and the rest is burned at constant pressure during the first part of the power stroke, as in the Diesel.

The dual cycle is particularly well adapted to engines with mechanical fuel injection, and results in an excellent combination of easy starting qualities, moderate pressures, high thermal and mechanical efficiencies, and large power output. The lowest fuel consumptions so far reported for oil engines, about 0.35 lb. per b.hp-hr., were made with engines operating on the dual cycle.

Engineers would gratefully welcome the publication of data and charts similar to those of this paper but applying to the dual cycle which is now being widely employed.

## Authors' Closures

F. O. Ellenwood. The authors are very grateful to those engineers who have contributed to the discussion, which is so essential for general progress in matters of this kind, but they also desire to express special thanks to Professors Goodenough and Upton who have taken considerable pains to work out the technical relationship involved in certain calculations and to express their opinions regarding many important points. All engineers who have given this subject careful thought are forced to realize that it is a very complex one.

Regardless of whether the work that has thus far been done by different investigators in Europe and in this country may be considered as a satisfactory base on which to establish a standard, it certainly must be true that the exchange of ideas and general study and discussion that comes from this work will in itself be of much value to the profession.

Considering the individual discussions, the authors believe that the arguments advanced by Professors Marks and Cross, that the time is not yet here when we should make these calculations, are well answered by Professor Allcut, who asks: "Where would we be today regarding the preparation of our steam tables, had we waited until we were sure of the proper values to use for both saturated and superheated steam?" In other words, engineers and scientists can never attain the ultimate in matters of this kind, but they can often take decided steps toward it. Professor Marks has undoubtedly presented an unduly pessimistic view of the situation regarding specific heats. In this connection, it seems to the authors very appropriate to quote from a paper by Sir Dugald Clerk, presented before the Institution of Civil Engineers, January 10, 1928, when he says in a discussion of this same subject: "The time has come for the application of accumulated knowledge to the substitution of real working fluids for the ideal properties which were necessary because of ignorance of the real."

The authors fail to appreciate, possibly as much as they should, the suggestion of Professor Marks that an air standard be substituted for the hot-air standard discussed in the paper. It is not altogether clear what particular advantage this would have because, as he says, "it would actually give correct values for the Diesel at the lower limit of power, that is, for the Diesel with no fuel injected." It is certainly true that most of us are much more concerned with a standard that applies to Diesels that are using at least some fuel.

Professor Cross raises the question of whether the specific heats of gases are seriously affected by the change in pressure involved in the internal-combustion motor. Taking his own reference (Jakob) on this subject, it is readily seen that for the temperatures and pressures involved in the internal-combustion motor, the effect of the variation in pressure on the specific heats is too small to be considered of any significance.

The result of the calculations of Herr Jakob show that for an increase of pressure of 500 lb. per sq. in. the increase in $c_p$ for air is about 7 per cent at a temperature of 32 deg. fahr. and about 1.2 per cent at a temperature of 482 deg. fahr., so it is fair to ask Professor Cross what he considers the increase might be at 1000 or 3000 deg. fahr. The variation in $c_v$ is roughly half as large as in $c_p$ at 482 deg. fahr. The same conclusion may be reached by consulting Glazebrook's "Dictionary of Applied Physics," vol. I, page 415, or by plotting the values given by Partington and Shilling in "The Specific Heat of Gases." In all of these references it will be found that for very *low temperatures* and for very *high pressures* the effect of pressure on the specific heat of gases is of great importance, but for the *pressures and temperatures involved in the internal-combustion motor*, the effect of pressure on the specific heat is quite negligible.

In the latter part of Professor Allcut's discussion, he questions the following statement occurring on page 7 of the original paper: "This available energy, as previously explained, can never be based logically on anything but the lower heating value for the internal-combustion motor." Professor Allcut apparently does not realize that it is one thing to talk about the heating value to be used in determining the net work or available energy of the ideal cycle involving a real mixture with variable specific heats, and an entirely different matter to talk about the heating value on which the efficiency of such a cycle may be based. All of the references that he gives regarding the most recent test codes in America and Europe have said nothing, so far as the authors can ascertain, about the use of the higher heating value for determining the rise of temperature of the mixture in an internal-combustion motor. The quoted statement of the authors certainly says nothing regarding the use of any heating value for the purpose of obtaining the thermal efficiency of any heat engine, ideal or real. When it comes to the question of computing the rise in temperature by the combustion of the fuel after compression in an internal-combustion motor, the case is entirely different from that involved in calculating efficiency.

The temperature at the end of compression is always so high that only a low heating value is available to produce a rise in temperature during combustion, but this in no way prevents the use of any other heating value agreed upon by engineers as the proper one on which to base the thermal efficiency of the engine, both ideal and actual. As Professor Goodenough says in his discussion: "In no phase of analysis of a cycle can the higher heat of combustion possibly enter into the calculation. It is only in the final step, the determination of the efficiency, that the high value functions." Professor Upton also makes the point clear that only the lower heating value can be used in the calculation of the rise of temperature of the ideal cycle, although he is a firm believer in the use of higher heating value for the thermal efficiency of the actual and ideal engine. The authors can appreciate Professor Allcut's viewpoint because they, as

well as many other engineers whom they know, have had to pass through the stage in which it is difficult for the mind to realize that a higher and lower heating value can both very logically be used in the same problem, one for determining the rise in temperature of the working substance, and the other for the determination of the thermal efficiency.

Mr. Baker refers to the use of steam with a quality of 95 per cent in an engine and states that we do not charge the engine with dry saturated steam in such case. This illustration is used in connection with his discussion of the ideal Otto engine that should be used as a standard with which to compare the real engine running with a deficiency of air. It seems to the authors that a little thought on this subject will indicate why the comparison is of no value, because the steam engine does not have any combustion of fuel taking place within the cylinder—and it is exactly this point, the combustion of fuel within the cylinder of the engine, that is involved. The authors believe that an ideal heat engine should be defined as one in which there is no loss of energy due to leakage, fluid or mechanical friction, heat transfer, or incomplete combustion of fuel. With this as a fundamental conception of what constitutes an ideal heat engine, whether the combustion takes place in the working cylinder or not, it is then apparent that the ideal cycle need never be calculated for any case in which there is insufficient air to support complete combustion. Since Mr. Baker has chosen to introduce an illustration involving steam, it is in order to call his attention to the fact that the ideal boiler with furnace is often used as a standard with which to compare the performance of the actual one. In such a case the ideal boiler furnace is supposed to be one in which there is just sufficient air supplied for the complete combustion of all the fuel used. The supply of sufficient air to support combustion would seem to be one of the most basic premises in any ideal combustion process. Just because an Otto engine may, on a rich mixture, possibly run cooler, start easier, stall less readily, or do a number of things that may be considered desirable in an automobile engine, need not alter our conception of what the ideal should be. It seems to the authors that running an Otto engine with a deficiency of air should show up in its decreased engine efficiency just as logically as running it with too much cooling water. If the ideal Otto is at times to have insufficient air for complete combustion of the fuel because it may be desirable to operate a real engine that way sometimes, why not also make our ideal engine one in which the loss to the water jacket is the same as in the actual case? Adiabatic processes and sufficient air for complete combustion are about equally basic in the ideal heat engine, as the authors see it. However, this question is of much interest in dealing with the Otto engine and undoubtedly is, as Professor Upton says in his discussion, "a matter of arbitrary choice with plausible arguments on either side."

Professor Schweitzer calls attention to a suggestion of Professor Langer's that the Diesel cycle be abolished altogether as a standard and that only the Otto be used, because many of the late Diesels have such an appreciable portion of the combustion taking place at constant volume. This suggestion probably merits careful consideration because of its technical value, but surely not because any present or prospective Diesel engine has given any evidence of causing embarrassment by having an indicated engine efficiency greater than 100 per cent.

Mr. Kates suggests that it might be desirable to make the calculations cover the dual-combustion cycle. Such calculations are even more complicated than those for the Diesel cycle, and it seems to the authors that it would be best to wait until certain questions regarding the Otto and Diesel can be considered further.

According to Professor Lichty, "the true performance factors" are now to be found in the Goodenough and Baker values. This statement will no doubt be received by the scientific world with the utmost interest, because it implies that no future work need ever be done on specific heats, dissociation, or any other of the many complex factors entering into the calculation of the ideal cycles of internal-combustion motors. It appears that Professor Marks and Professor Lichty represents the two extremes in this respect, because the latter apparently thinks that the last word has been said on the subject, while the former believes that such calculations should not be attempted now because our knowledge is too incomplete.

The authors believe that Professor Goodenough cannot justify his assumption that in the ideal case the residual gases may be considered as expanding at constant temperature. If instead of his isothermal expansion these residual gases be considered to expand adiabatically with an average value of $\gamma = 1.3$, the weight will be about 50 per cent greater than the value 0.604 lb. per lb. of fuel, as calculated by him for case 11.

The authors made their assumption regarding this very complicated question of how to estimate the weight of residual gases after considerable effort had been made to try to find a reasonable method of calculation. That their method is not without some merit, aside from its simplicity, is shown in the discussion of Professor Upton and also by the fact that Professor Goodenough concedes that this method gives results that "agree fairly well with the conditions in the actual engine," although he questions the logic of making the residual weight agree in the ideal and actual cases. Some engineers may believe that the weight of residual gases is not of sufficient importance to justify serious consideration, but the calculations given in Professor Goodenough's discussion point clearly to the necessity of care in making this estimate, especially when dissociation is considered. His figures show $T_3$, the absolute temperature at the end of combustion in the ideal Otto, to be 257 deg. higher with his value of the residual than with the authors', when neither considers dissociation. This region of temperature (5000 or more deg. fahr. absolute) is one where relatively small changes of temperature produce large changes in dissociation. Consequently, it seems to the authors that both the overly high temperature, from too little dilution, and overly high dissociation, result in lowering of the Goodenough and Baker cyclic efficiency unduly. In general the effect of assuming too small a dilution of the fresh charge with spent gas causes a multiple error in understatement of cyclic efficiency, if dissociation is considered.

Professor Upton has pointed out that the authors' assumption about residual gases is, essentially, that for all mixtures and compression ratios the clearance is filled with exhaust gas at 1320 deg. fahr. absolute. He has also outlined a logical ideal process by which the residual gas left in the clearance runs down in temperature and pressure from the condition at the end of the expansion line to the condition at the end of the exhaust stroke. That his statement of this ideal process is reasonable can be seen by studying the measured temperatures of the last exhaust gas escaping in actual cases, as given in Bulletin No. 150 of the University of Illinois, by Rosecrans and Felbeck, entitled "A Thermodynamic Analysis of Gas-Engine Tests." Their results show that the actual residual gas temperatures were found to be from 1260 to 1760 deg. fahr. absolute, with various mixture ratios, fuels, and compression ratios. These actual temperatures are of course somewhat lower than the ideal, because of the heat transfers during combustion and expansion in the real engine.

Professor Goodenough points out that the computations for the Diesel cycle are affected but slightly by the different weights of residual gases, but that for this cycle the chief difference is in the interpretation of the combustion process. The authors are not convinced of the superiority of his method, especially since

he assumes the fuel to be "completely vaporized before entering the cylinder." In this connection it should be remembered that the heating values of oil as determined by calorimeters sometimes vary more than 1 per cent for different samples from the same tank.

Even though in the past it may have been considered by some engineers a relatively simple matter to specify the processes and working substance involved in ideal cycles, it should now be recognized that for the internal-combustion motor both of these items afford some chance for differences of opinion, and possibly the arguments that can be advanced for two opposite viewpoints may be equally valid. In such a case further study and consideration of the subject by competent engineers will undoubtedly assist in making arbitrary, but satisfactory choices, where they need to be made, in order to effect standardization.

F. C. Evans. In regard to cases of engines operating with a deficiency of air, there is a very evident and not entirely unexpected difference of opinion. Rather than argue further in support of our point of view as expressed on the first page of the paper, namely, that such cases should be compared with a perfect-mixture standard, the present author prefers to indicate a more indirect but also more important conclusion. The value of this and similar work on standards of performance for internal-combustion engine is minimized unless within the next few years a very widespread adoption of engine efficiencies for internal-combustion engines results. Differences of opinions of the character just mentioned would necessarily have to be adjusted before these standards would be accepted for general use. The authors of this paper prefer to keep the goal in mind, namely, widespread use of engine efficiencies in connection with internal-combustion-engine tests, and would sacrifice ideas of the preceding character in the face of real opposition rather than defeat the ultimate purpose by excessive resistance on some debatable points. This disagreement shows the necessity of competent organized action to compromise on some points as the next step toward general use of these engine efficiencies.

Professor Goodenough demonstrates that the quantity of residual gases influences the results. And the present author believes every one is in agreement that this is a difficult matter to determine accurately. It is obvious that our assumption is only approximate. However, Professor Goodenough, in his specific problem, bases his residual-gas weight on a clearance gas temperature of 3521 deg. fahr. abs., which is much too high in the opinion of the authors.

In this connection Professor Upton presents another idea, namely, that this residual-gas quantity is greater with a two-cycle engine than with a four-cycle engine, justifying to some extent using a figure too high for the latter type of engine in order that the same standard may be applied to the two-cycle type without too great an error.

Dissociation is another factor that obviously must be subjected to some compromise action. The authors have stated their position in this matter fully in the paper and it would be futile to discuss the matter further here. An arbitrary ruling by a competent group would settle an issue that otherwise will be open to continual argument, provided all would abide by the decision of such a committee.

The authors are aware that the heating value of fuels depends on the temperature at the start of combustion, as Professor Goodenough points out. This factor was ignored because an average heating value was arbitrarily assumed for each fuel, which value being only an average will undoubtedly be too far from the actual heating values on some tests to justify too great refinement. As Professor Goodenough points out, there is a relatively unimportant difference.

# Oil-Spray Investigations of the N.A.C.A.

## Oil-Engine Performance—Combustion Losses—Value of Research—Oil-Spray Investigations of the National Advisory Committee for Aeronautics—Photographic Records of Fuel Sprays and Graphs for Use in Studying Spray Characteristics and Fuel Injection in High-Speed Engines

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The development of the oil-burning engine since Dr. Diesel built his first oil engine in 1897 (1)[2] has gone forward in several directions. Today we find that, of the several types of internal-combustion engines burning fuel oil, the so-called oil engine has gained much favor and is being manufactured in increasingly greater numbers than is the Diesel or air-injection engine, the semi-Diesel or hot-bulb engine, or those engines carbureting or injecting their fuel oil into vaporizing manifolds and igniting it by electric spark as in the gasoline engine. This increase in popularity of the oil engine is well deserved, because its theoretical thermal efficiency is about four per cent higher and its accessory power requirements about seven per cent lower (2) than its air-injection competitor, and because its construction is more simple.

### Oil-Engine Performance

However, the practical success of the oil engine does not depend solely upon these factors. The detail design and arrangement of the combustion chamber, valves, and pistons, and the degree, direction, and timing of the turbulence they produce, have marked effects on the performance of an engine. The compression ratio, the timing and rate of injection, and the promptness and thoroughness with which the oil is atomized and mixed with the cylinder air, control to a large extent the lag and speed of both ignition and combustion. Oil-engine performance is therefore not proportional to the efficiency calculated from the compression ratio, as is nearly true for gasoline engines, but is dependent upon the success with which the engine design and all the details of injection are carried out.

If indicator cards from many oil engines are examined it will be found that they usually differ considerably. The compression pressure may be as low as 280 lb. per sq. in., or as high as 550 lb. per sq. in.; the maximum cylinder pressure may vary from 500 to 1000 or more lb. per sq. in., and the type of combustion will range from that at practically constant pressure to that at practically constant volume (3 to 9). This extreme variation in design and in the resulting combustion of the fuel is partly accounted for by the effects of increasing the engine speed in the effort to adapt the oil engine to railroad, automotive, and aircraft service (10 to 20). It is strong evidence, however, that the problems of burning fuel oil in engines are not only viewed differently by different designers but, at the present time, are not perfectly understood and lack solutions that permit full attainment of the desired performance.

### Combustion Losses

Simple calculations show that if there were no thermal losses sustained in transforming fuel oil into power we should obtain an indicated horsepower-hour for a consumption of about 0.14 lb. of oil. There are, however, three thermal losses that increase this ideal fuel consumption considerably. They are the heat lost, first, in the exhaust gases, second, in the cooling water and other radiation with complete combustion, and, third, the heat energy lost because of either "late" or incomplete combustion. If the thermal losses incident to the magnitude and timing of the cylinder pressures and temperatures in the construction of the theoretical indicator card amount to 40 per cent, then the efficiency of the cycle is 60 per cent and, without other losses, we should obtain an indicated horsepower-hour for a consumption of about 0.23 lb. of fuel oil. If the cycle efficiency is only 50 per cent, we should still obtain an indicated horsepower-hour for 0.28 lb. of oil.

While the author has recorded fuel-oil consumptions down to 0.26 lb. per i.hp-hr. in the experimental aircraft single-cylinder oil engines of the National Advisory Committee for Aeronautics, running at 1600 r.p.m., this figure was for one-quarter load (21, 22). At the same engine speed and at an approximate commercial full load, taken at an air-fuel ratio giving 112 lb. i.m.e.p. with 50 per cent excess air, the fuel consumption was 0.35 lb. When the load was further increased, as is necessary in aircraft engines, to an air-fuel ratio giving only 15 per cent excess air, the fuel consumption increased to around 0.44 lb. per i.hp-hr. Many large-size, slow-speed, commercial oil engines have fuel consumptions that are quite comparable to the values quoted for the same percentages of excess air. These increases in fuel consumption over the low theoretical value of about 0.26 lb. are largely the result of either late or incomplete combustion of the injected oil, and may be laid directly at the doors of improper design and our present imperfect knowledge of oil injection.

### Value of Research

It has been found that if good performance is to be obtained in an oil engine, the most careful study must be made of all the processes and requirements of oil injection, atomization, distribution, ignition, and combustion. For example, if the injection of the oil is at too high or too low a pressure, or its rate or timing is unsuited to the desired indicator card; or the atomization is too coarse to permit clean combustion in the time available, or is too fine and lacks penetration; or if the distribution of the oil particles in the spray is poor so that the spray contains very lean and very rich portions, and is not properly aided by turbulence; or if the ignition is late so that a large part of the fuel charge may burn at practically constant volume and cause excessive cylinder pressures, or if it is slow and results in after-burning; then the combustion will not be complete, controlled, nor properly timed, and the engine performance will be low. The value of research on oil sprays therefore lies in the discovery and practical investigation of all of their atomization, distribution, and combustion characteristics.

### Methods of Investigating Oil Sprays

There are six major methods of studying oil sprays. These are: (1) Injection into the atmosphere; (2) injection into

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[2] Numbers in parentheses indicate similarly numbered references in the bibliography published at the end of the paper.

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liquids; (3) injection on to targets; (4) injection into cold compressed gases; (5) injection into heated compressed air and (6) injection into engines, i.e., actual engine tests. Each method has both advantages and disadvantages and is of different ultimate value.

1 *Injection into Air.* All oil-engine engineers have undoubtedly studied fuel sprays by observing them in the atmosphere. While this method is often misleading as to the size and shape of a spray when it is injected into an engine (23), many of the variables are proportional for different nozzles and valuable preliminary information may be obtained. Kuehn, in Germany (24), sprayed a small quantity of oil on a sooted glass and calculated the average diameter of the fuel particles from their total weighed volume and their total counted number. By making many tests he determined the approximate effects of injection pressure and three nozzle designs upon atomization. Sauter (25, 26) has reported a method for calculating the average size of fuel particles from the photometric diminution of light passed transversely through a widely dispersed spray. A second method suggested by Sauter consists in calculating the particle size from the amount of electrical energy carried from a charged nozzle by a spray in unit time.

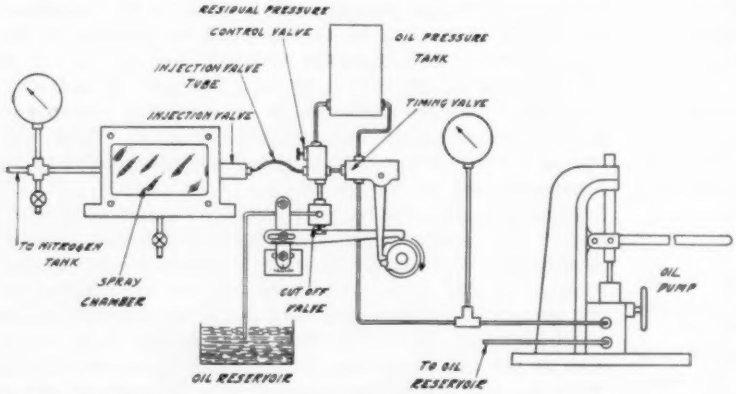



FIG. 1 DIAGRAMMATIC ARRANGEMENT OF APPARATUS FOR PRODUCTION AND CONTROL OF SPRAY

A considerable amount of preliminary work on injection into the atmosphere was done by the author before the Committee's present high-speed spray-photography equipment was completed. This consisted in the observation or measurement of the maximum penetration, relative atomization, shape, and combustion characteristics of Diesel-oil sprays. The effects of nozzle adjustment and injection pressure were pronounced. The maximum penetrations ranged up to about sixteen feet; the atomization ranged from large particles which fell rapidly to almost invisible particles that quickly disappeared by evaporation in the air; the spray shape varied from long, thin streams to full, bushy sprays; and the combustion from smoky, red flame to clean, intense white flame. Spray velocities and coefficients of discharge were calculated from the measured rate of fuel discharge. The plotted results gave smooth curves for all of the variables. The oscilloscope was also used, both on engines and on special injection-system test equipment, to permit slow motion study of the start, growth, and cut-off of oil sprays produced by various injection valves and pumps.

2 *Injection into Liquids.* The study of sprays by injection into liquids has been more limited, largely because of the obvious differences between gases and liquids, which render the results of uncertain value, and because of the difficulty of making practical observations and measurements. Some of these difficulties have, however, been largely overcome by special means. Hauser and Strobel (27) caught sprayed fuel particles in a film of glycerine on a glass and measured their diameters with a microscope. Woltjen (28) injected fuel sprays into compressed air in a steel bomb, catching the fuel particles in a solution consisting of 70 per cent of distilled water and 30 per cent of "Queol D," a tanning extract, in the bottom of the bomb. This solution held the oil particles in suspension and permitted photomicrographs and therefore size measurements to be made. By injecting with different fuel pressures, with and without injection air, and with different air pressures in the bomb, Woltjen obtained considerable data on the factors affecting atomization. Shepherd (29) and others injected oil sprays directly into water and observed their relative penetrations. If the effects on the density and viscosity of liquids on oil sprays were determined, as has been done for gases (30), this general method could be extended and would permit the practical determination of spray-particle size for many test conditions.

3 *Injection on to Targets.* The injection of oil sprays on to targets has probably been practiced to a greater extent than injection into liquids. The targets are mounted on the fly-wheel of the engine, or on special injection-system test equipment, and one or more sprays made to impinge against them. While this method is of little value in the determination of the atomization or penetration of an oil spray, it does give important records of the lag, rate, and duration of injection. By injecting at various loads and speeds, with various injection-valve adjustments or injection-tube lengths and diameters, and having means to measure the fuel pressures and discharge quantities, a fuel-injection system may be quite accurately and completely calibrated. Considerable experimentation by this method at the Committee's Langley Field laboratory (31 to 33) has yielded valuable information and disclosed injection phenomena that have materially aided in the design and practical application of various injection systems to aircraft-type oil engines.

4 *Injection into Unheated Compressed Gases.* Extended investigations on oil sprays have generally been carried out by injecting them into chambers containing unheated air or other gases under pressure. Some investigators have built heavy glass bombs or cylinders and observed the retarding effects of various gas pressures upon the injected sprays. Riehm (34) constructed a chamber with an impact plate and magnetically controlled balance with which to measure the kinetic energy of fuel sprays. By injecting his sprays under various pressures, and varying the chamber gas pressure and the distance between the nozzle and the impact plate, he obtained valuable data on the variation of spray energies, velocities, and penetrations with nozzle design and various operating conditions. This method of oil-spray research with modifications and additions was independently recommended to and adopted by the Pennsylvania State College in 1923 and 1924. The National Advisory Committee for Aeronautics perfected its present apparatus for the study of fuel sprays in the fall of 1924 (35). The photographic method is used. A spray chamber with windows, means for injection control of the spray and its intense, high-speed intermittent illumination and recording on photographic film, during its development, is employed. This equipment and the results of some fundamental investigations will be briefly discussed later.

5 *Injection into Heated Compressed Air.* The study of oil sprays by injection into heated compressed air has, in general, been limited to the determination of ignition temperatures and the time lag between injection and ignition. Many experi-

menters, realizing the importance of the auto-ignition temperature in the design and operation of oil engines, have conducted extended investigations on many fuels. Dixon, Holm, Moore, Wollers and Ehmcke (36 to 38), and others have made ignition-point determinations at atmospheric pressure by dropping the fuel oil on to hot plates, or by injecting it into heated air or oxygen. Alt (39) repeated and extended certain researches on the ignition point at atmospheric pressure on many oils, using two ignition-point testers, and made comparisons of his results with the approximate ignition temperatures required in engines. Hawkes (40) sprayed shale oil into a chamber containing heated compressed air and obtained what he termed "practical ignition temperatures" by measuring the time lag between injection and ignition for various test temperatures. The ignition lag for his sprays varied from 0.16 sec. at 630 deg. fahr. to 0.007 sec. at 930 deg. fahr. Tausz and Schulte (41) determined the ignition temperatures, chiefly in air, of several oil-engine fuels, and mixtures of these fuels, by two methods and for various pressures up to about 540 lb. per sq. in. The first method determined the ignition temperature of the fuels when dropped into heated air at constant pressure, and the second method the ignition temperature when the fuels were sprayed into heated air, the pressure of which was increasing as in an actual engine. Their data cover a wide range of conditions and check engine tests closely. The National Advisory Committee for Aeronautics has recently undertaken the design and construction of additional oil-spray ignition and combustion apparatus to be used with its present high-speed spray-photography equipment. This combined equipment will be employed to study the effect of air pressure, temperature and turbulence, combustion-chamber shape, exhaust-gas dilution, and all the variables of injection, atomization, and distribution upon the ignition temperature, lag of auto-ignition, and rate of combustion of oil sprays.

6 *Injection into Engines.* The investigation of oil sprays by injection into an engine usually consists in determining the engine performance. The information obtained in engine tests, though of vital importance in analyzing the complete machine, is not directly applicable to the study and analysis of oil sprays because of the influence of the combustion-chamber design and other engine variables. Junkers, however (6), has employed fused-quartz windows in an engine and recorded the timing and progress of combustion for different conditions. No definite data from this work have as yet been received. While this method of oil-spray study may be adapted to specific engines, the effects of any single variable may easily be hidden by a number of other difficult-to-control and interdependent variables in the engine, and the method is costly for fundamental research.

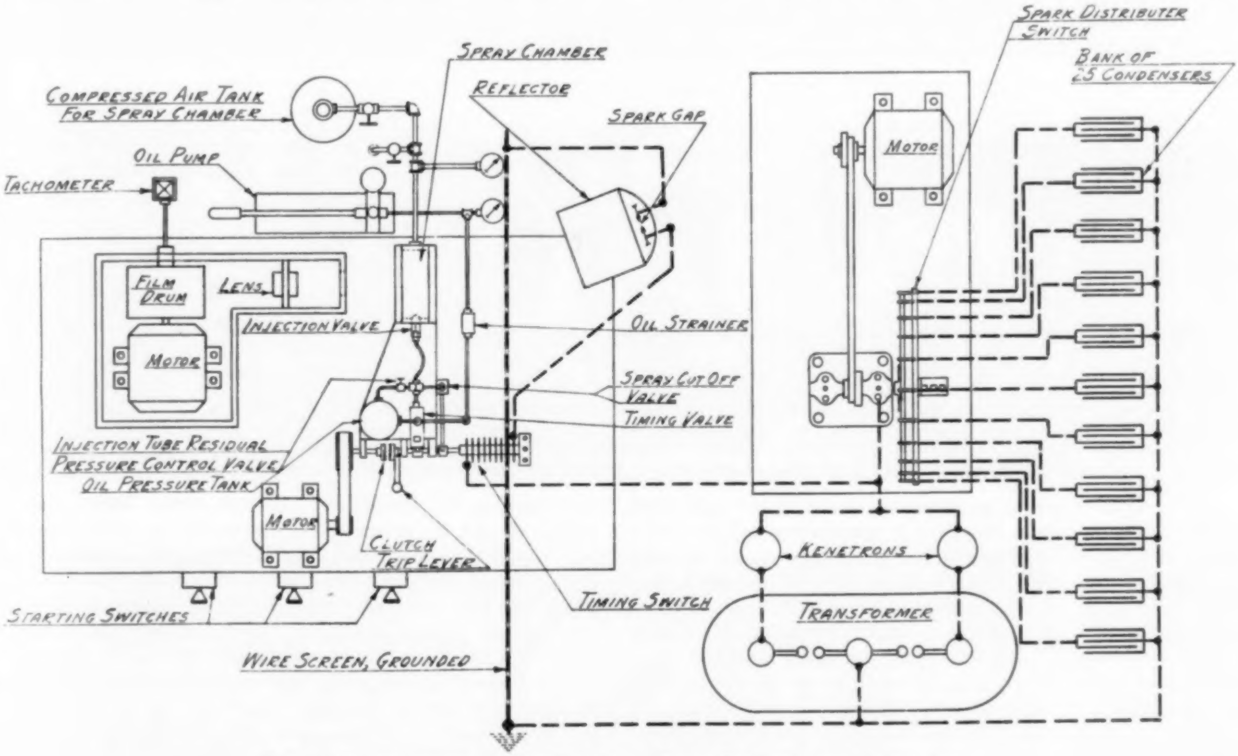



Fig. 2 Diagrammatic Arrangement of Spray-Photography Apparatus

## N.A.C.A. Oil-Spray Investigations

The present method used by the National Advisory Committee for Aeronautics to study the characteristics of oil sprays, as previously stated, is that of injection into unheated gases under pressure in a chamber, and photographing the rapidly moving spray at progressive stages from the instant of its appearance at the nozzle, through spray cut-off, to its practically complete development and distribution. The equipment which permits the taking of these ultra-high-speed moving pictures of oil sprays consists of three major parts: the spray-production apparatus, the spray-illumination apparatus, and the spray-recording apparatus.

The spray-production apparatus is shown in Fig. 1. It includes a high-pressure hydraulic hand pump with which the oil is pumped to the test pressure in an oil pressure tank; a timing valve which controls the oil discharge from the oil pressure tank to the injection valve, and a spray cut-off valve which controls the period of injection. A camshaft is provided to operate the timing and cut-off valves and to control

the speed of operation. The camshaft is driven at the required test speed for one revolution by a special clutch and disengaging mechanism, thus producing only one spray. An initial pressure-control valve permits the investigation of various initial pressures in the injection tube. Injection valves are used which permit the investigation of various stems, nozzles, and operating pressures. A spray chamber with large optical-glass windows is used which permits both the observation and photographing of the spray when injected into any selected gas. The gas may be under pressure up to 600 lb. per sq. in. The spray chamber is designed to permit the study of mechanically and hydraulically operated injection valves, and of sprays up to six inches in length. Usually only single sprays are injected into the spray chamber for study with this apparatus.

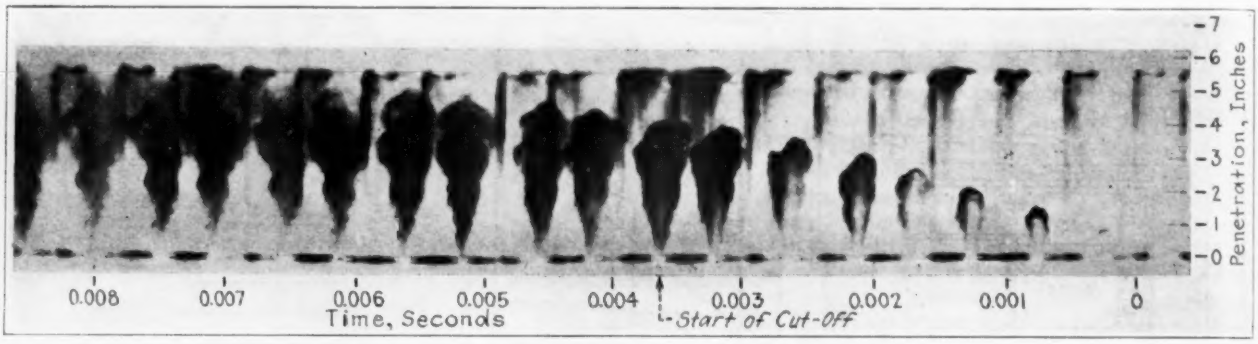



FIG. 3 MEDIUM CENTRIFUGAL SPRAY FROM INJECTION VALVE NO. 7
(Diesel oil of 0.85 sp. gr. injected at 8000 lb. per sq. in. into compressed air at 200 lb. per sq. in.)

The spray-illumination apparatus is shown in the right half of Fig. 2. It includes a 100,000-volt transformer and kenotrons with which to charge 25 large-capacity condensers, and a large-diameter, motor-driven, rotary distributer switch which permits the charging and discharging of the condensers in sequence up to a rate of about 4000 per second. A reflector is provided to focus the high-intensity sparks from the condensers upon the spray. A master condenser switch, which is operated by the spray-control camshaft, coordinates the occurrence of the sparks with the occurrence of the oil spray in the spray chamber. The duration of each electric spark is less than one millionth of a second, so that even though a spray may be traveling with a velocity of 500 ft. per sec., the resulting spray image on photographic film is sharp and well defined.

The spray-recording apparatus is shown in the left quarter of Fig. 2. It consists essentially of a large-aperture, high-grade photographic lens for focusing the spray image upon a photographic film, a film drum which rotates the film at high speed, and a light-tight camera box enclosing the lens and film drum. The speed of the film past the lens may range up to 300 or more feet per second, the speed being adjusted to obtain sufficient spacing between the spray pictures to prevent overlapping.

A reproduction of a photographic record of a medium centrifugal oil spray obtained with the N.A.C.A. spray-photography apparatus is shown in Fig. 3. The penetration in inches for various times after the start of injection may be measured from the ordinate and abscissa scales given. The start of cut-off is marked. The spray near the injection valve immediately following cut-off has little penetrating power and tends to mask the cessation of injection in this record. The cut-off, however, is controlled by mechanical adjustment and may be checked by inspection of records of sprays injected into air at atmospheric pressure such as are shown in Figs. 4 and 6.

A considerable amount of information may be obtain from these photographic spray records. They may be studied visually as to their peculiarities and general contour. The point of cut-off may be established as noted above. Phenomena occurring after cut-off, such as dribbling, secondary discharges, low penetration, and twisting of the spray, may be studied. The relative atomization for different sprays may be estimated. The shape, position, and possibly the causes of the small clouds of oil particles thrown out from the main spray, as shown particularly in Fig. 6, may be investigated. The importance of such irregularities in oil sprays should not be underestimated as they may readily become the foci of ignition.

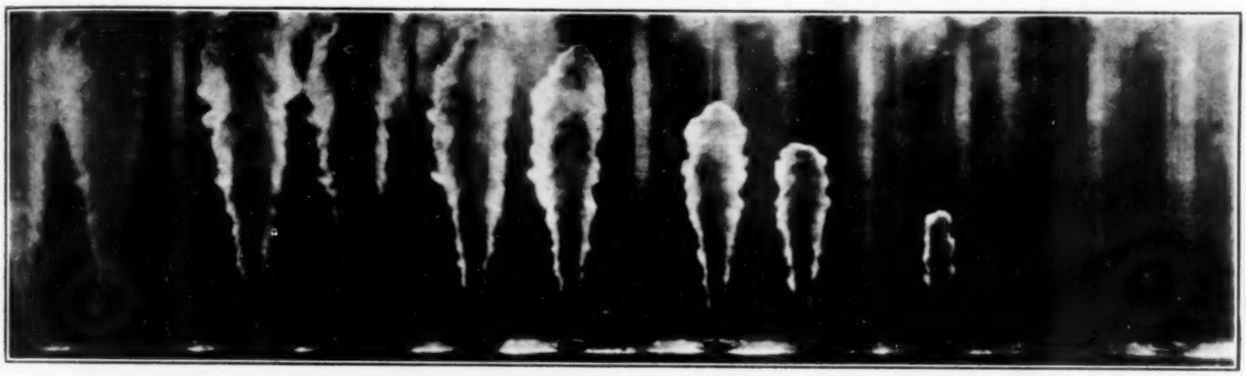
The spray images on the film may be measured, and, since the photographic reduction and speed of the film are known, the penetration may be plotted against time. From such penetration-time curves the velocity and deceleration of the spray tip may readily be computed. The spray-cone angle may be measured, and, by summing the volumes of a number of disks into which the spray may be divided, the volumetric growth of the spray may be approximately determined. By making other tests in which many sprays are caught in a container and weighed, the quantity of oil in one spray may be computed. If the volume of a spray at cut-off be divided by the volume of the oil injected, the resulting figure gives the number of times the liquid-oil volume has been made to increase by injection and atomization under any particular set of conditions. Such data provide a direct measure of the distribution of oil sprays.

The N.A.C.A. spray-photography apparatus is equipped to study either mechanically or hydraulically operated injection valves. The effects of injection pressures up to 12,000 lb. per sq. in. and of spray-chamber gas pressures up to 600 lb. per sq. in. are investigated. Different fuels have been employed and several gases at various pressures in the spray chamber have been used in studying the effects of fuel characteristics and of gas density on sprays. Several designs of injection valves and various stems, nozzles, and injection tubes have been investigated in determining the effects of injection-valve and injection-system design.

Several investigations on the various characteristics of oil sprays have been completed to date. These can only be mentioned briefly. The first research determined the discharge characteristics of a mechanically operated injection valve with a 0.0155-in. round orifice. Diesel oil was discharged through this orifice at pressures up to 8000 lb. per sq. in. into air at atmospheric pressure and into nitrogen at pressures up to 300 lb. per sq. in. The results have been published in terms of spray penetration, velocity, and deceleration in N.A.C.A. Report No. 222 (42).

Fig. 4 shows a set of reproductions of photographs similar to those taken in the first research. These oil sprays were obtained by discharge through a 0.022-in. round orifice installed in an auto-

Chamber Pressure, Atmospheric



Chamber Pressure, 200 Lb. per Sq. In.

Chamber Pressure, 400 Lb. per Sq. In.

Chamber Pressure, 600 Lb. per Sq. In.

Fig. 4 Spray Photographs Showing Discharge of Diesel Oil Through a 0.022-In-Diameter Orifice
(Injection pressure, 8000 lb. per sq. in.; no jet rotation.)

matic injection valve, and are much like those published in N.A.C.A. Report No. 222. The high rate of penetration for injection into air at atmospheric pressure and the appearance of this spray should be noted, as they illustrate the manner of its development and provide a means for visualizing one's oil sprays when observing them in the air. The pronounced decrease in penetration, the increase in spray cross-section, the small irregularities, and the appearance of greater atomization of the sprays injected into air at 200 or more pounds per square inch indicate some of the effects of a dense gas. The penetration-time curves for the 0.0155-in. orifice used in the first research, for injection pressures from 2000 to 8000 lb. per sq. in. and for spray-chamber gas pressures up to 300 lb. per sq. in., are reproduced in Fig. 5.

The second research determined the factors affecting the air. Had these sprays been observed only for the case of injection into air, it might have been assumed that their shape would remain the same when injected into an engine cylinder. This assumption would probably result in a misfit between the spray and combustion chamber, and consequently in inferior engine performance.

The variation of penetration and spray-cone angle for different amounts of centrifugal force applied to the oil in the jet are shown in Fig. 7. The better maintenance of penetration for the sprays produced by high centrifugal force, even when injected into air at 400 lb. per sq. in. pressure, is shown by the two penetration curves.

Fig. 8 shows the effect of centrifugal force on spray distribution. A non-centrifugal spray was found to have about

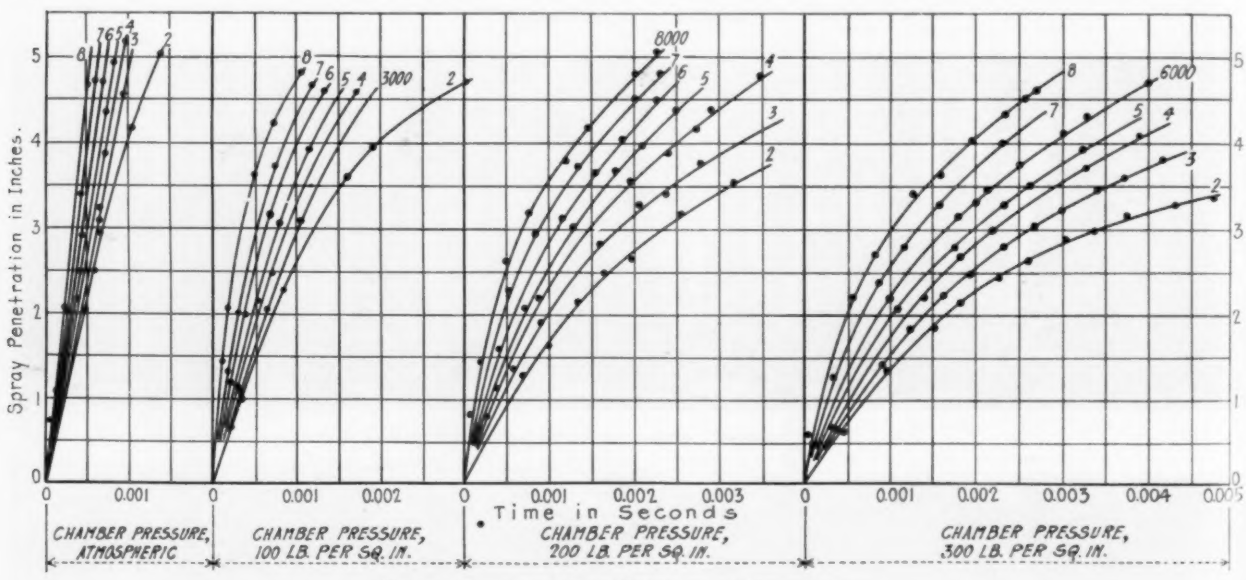



Fig. 5 Effect of Fuel Pressure on Penetration
(Injection pressures, 2000 to 8000 lb. per sq. in.; orifice diameter, 0.0155 in.)

exact reproducibility of oil sprays and the phenomena of secondary discharges after cut-off. The results have an important bearing on the smooth and reliable operation of oil engines, and have been published in N.A.C.A. Report No. 258 (43).

The third research determined the effects of the several factors that control the efficiency of discharge, atomization, and distribution of centrifugal-type injection valves. The results are given in terms of spray penetration, velocity, volume, and distribution as controlled by the diameter and length of the orifice, the position of the seat, and the area and pitch of the centrifugal grooves.

Fig. 6 shows a series of reproductions of photographs taken of a high-centrifugal-force spray. The sprays were produced by passing the oil through 23-deg. helical grooves, turned on the end of the valve stem, just before its discharge through a 0.040-in. orifice. The relatively low penetration and large spray-cone angle for the case of injection into air at atmospheric pressure are noteworthy for comparison with the non-centrifugal sprays of Fig. 4. It may be observed that this spray appears to be hollow and very well atomized. Cut-off has taken place between the fifth and sixth pictures. The advance of the end of the spray is slow, thus giving evidence of the low penetrating power of atomized oil when not driven forward by the continuance of the jet.

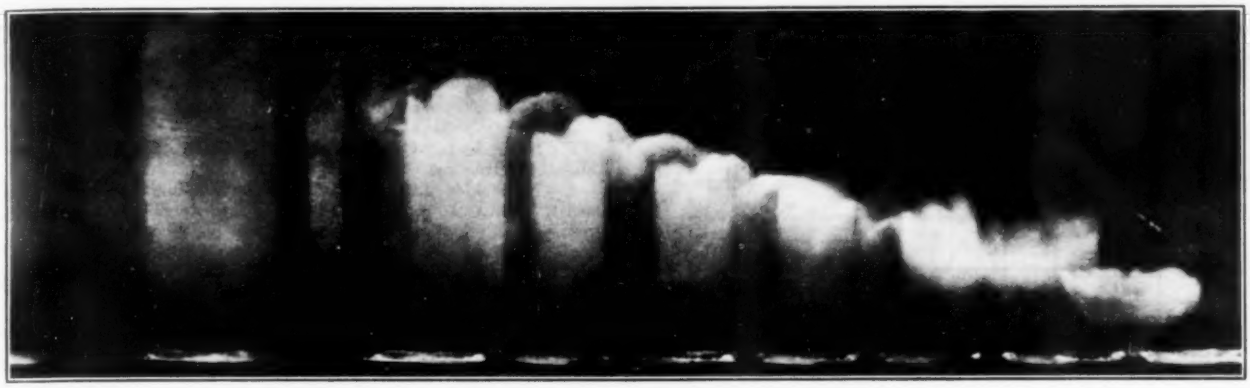
The great value of photographic spray records is evident on inspection of the sprays for the case of injection into dense

500 times the volume of the liquid oil in the spray 0.004 sec. after its appearance at the nozzle. When centrifugal force was applied to the jet under similar test conditions the spray could be distributed throughout a volume about 1000 times that of the liquid oil. This increase in distribution is obtained at the expense of some penetration, but the better mixture obtained with the air, and the finer atomization, aid combustion at the higher engine speeds. The results of the complete investigation are published in N.A.C.A. Report No. 268 (23).

The fourth research determined the effects of the viscosity and specific gravity of the fuel used on spray characteristics, and of the injection of Diesel-engine fuel oil into nitrogen, carbon dioxide, and helium at various pressures.

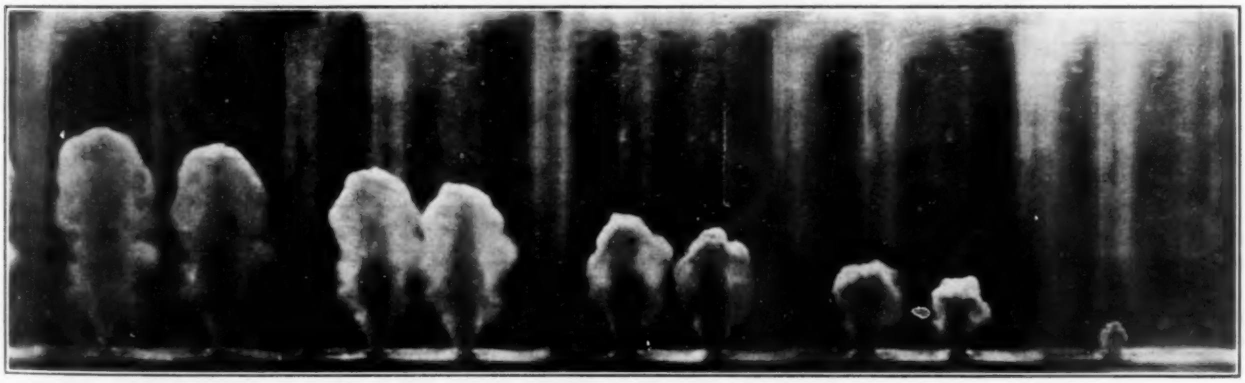
The effects of fuel characteristics on sprays were studied by injecting gasoline, kerosene, Diesel-engine fuel oil and a furnace fuel oil through the same injection valve into nitrogen in the spray chamber under the same test conditions. The specific gravity of these fuels ranged from 0.70 to 0.90. It was found that the penetration increased with specific gravity, but there was a corresponding decrease in the spray-cone angle and in the distribution. These results and the pronounced effects of high centrifugal force on the penetration, spray angle and distribution of sprays produced with these four fuels are shown in Fig. 9.

Although unconfirmed by engine tests, the advantages of increasing the distribution of heavy-oil sprays by means of

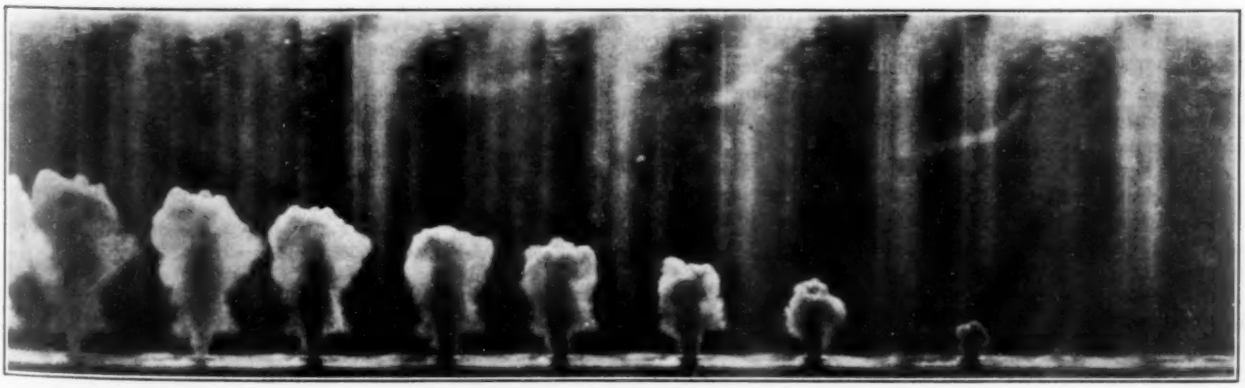


Chamber Pressure, Atmospheric

Chamber Pressure, 200 Lb. per Sq. In.



Chamber Pressure, 400 Lb. per Sq In.



Chamber Pressure, 600 Lb. per Sq. In.

Fig. 6 Spray Photographs Showing Discharge of Diesel Oil Through a 0.040-In-Diameter Orifice
(Injection pressure, 8000 lb. per sq. in.; high jet rotation.)

centrifugal force are clearly indicated by comparisons of the data for non- and high-centrifugal injection. While the penetration for the 0.90 specific gravity fuel decreased from 7.4 in. after 0.004 sec. to 5.45 in. with the application of centrifugal force, a decrease of 26.3 per cent, the distribution increased from 460 to 980, an increase of 113.0 per cent. Under the same conditions the penetration of gasoline decreased 33

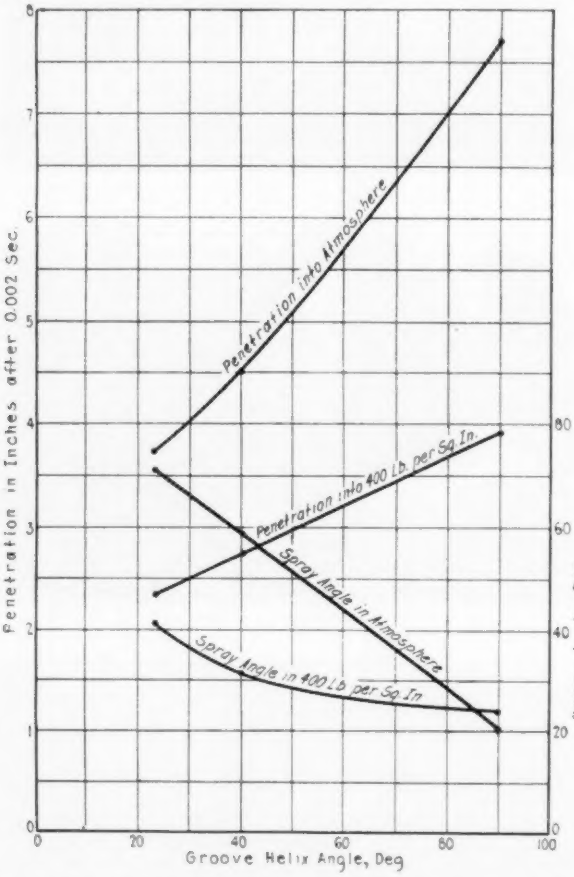



FIG. 7 EFFECT OF GROOVE HELIX ANGLE ON CENTRIFUGAL SPRAYS
(Injection valve No. 7; orifice diameter, 0.022 in.; injection pressure, 8000 lb. per sq. in.)

per cent with the application of centrifugal force and the distribution increased only 83 per cent.

The penetration of Diesel-engine fuel-oil sprays injected into nitrogen, carbon dioxide, and helium are shown in Fig. 10. This graph gives cross plotted data from several tests such as are presented in the insert. Since the experimental data lie on smooth curves when plotted against absolute gas density, oil-spray characteristics are dependent upon this factor rather than upon the gas pressure only. The data show that the effects of gas viscosity are negligible. A report is being prepared on the complete investigation.

A fifth research is nearly completed on the factors controlling the occurrence and velocity of pressure waves in injection systems for a large range of conditions, and the program for a sixth research on the factors controlling the exact action, injection lag, operating pressures, and fuel-delivery rates of injection valves is being formulated. Reports on these investigations will be published in the future.

By means of such photographic records of fuel sprays produced by various injection-valve designs, different fuels, and different pressure conditions as are presented in this paper, and by means of the graphs developed from them the characteristics of sprays for oil engines may be studied from many viewpoints, and the injection of fuel into the cylinders of high-speed engines perfected.

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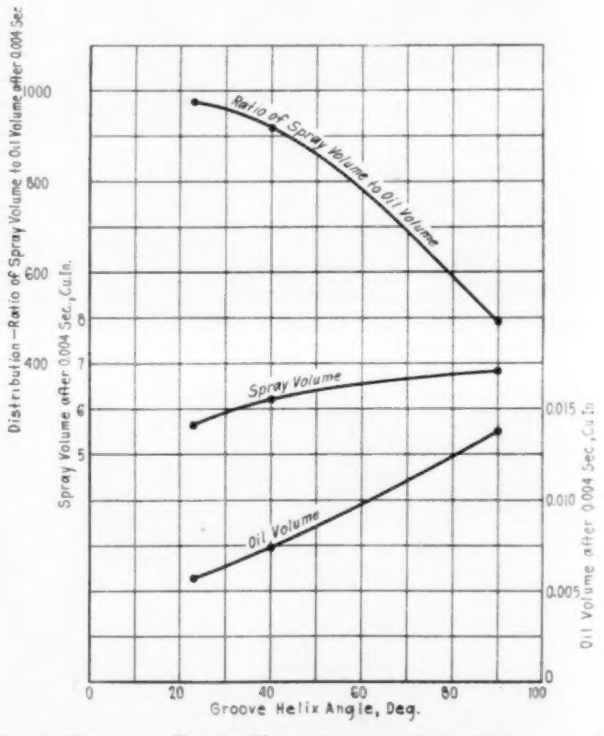


FIG. 8 EFFECT OF GROOVE HELIX ANGLE ON SPRAY DISTRIBUTION
(Injection pressure, 8000 lb. per sq. in.; chamber pressure, 200 lb. per sq. in.; orifice diameter, 0.022 in.; specific gravity of fuel, 0.85.)

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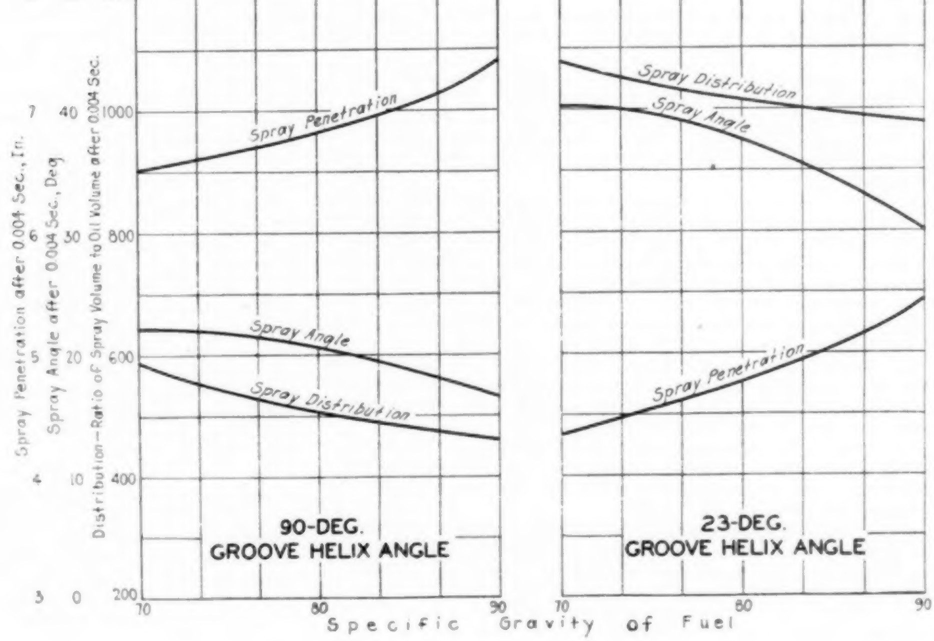


FIG. 9 EFFECT OF FUEL DENSITY ON SPRAY DISTRIBUTION

(Injection pressure, 8000 lb. per sq. in.; chamber pressure, 200 lb. per sq. in.; orifice diameter, 0.022 in.)

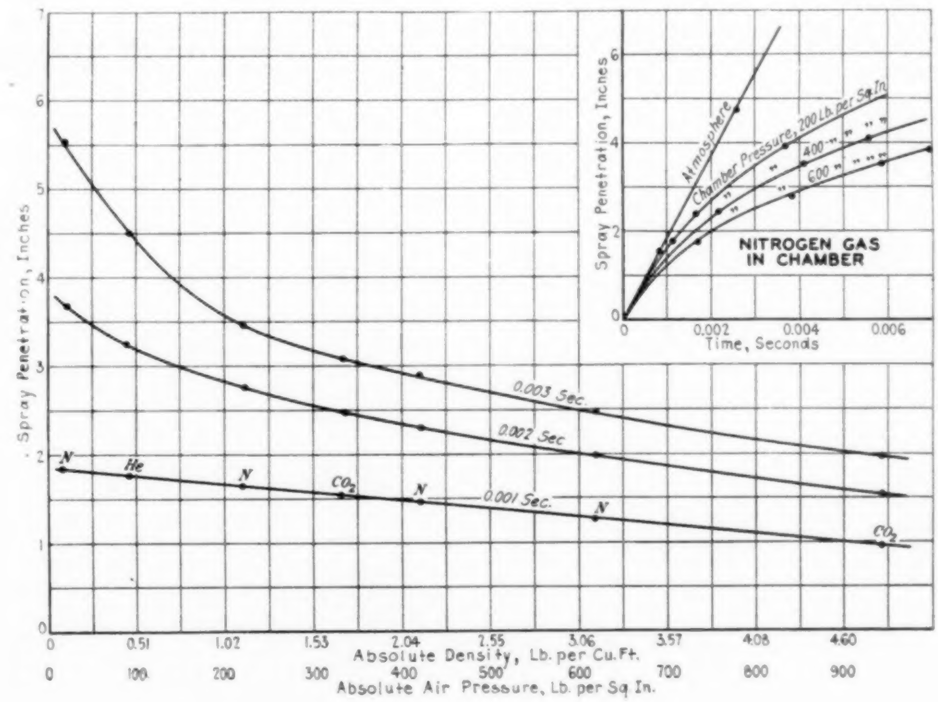


FIG. 10 EFFECT OF GAS DENSITY ON SPRAY PENETRATION

(Injection valve No. 7; 23-deg. spiral grooves; injection pressure, 8000 lb. per sq. in.; fuel used, Diesel oil of 0.85 sp. gr.; gas in spray chamber: nitrogen, carbon dioxide, or helium.)

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# Manufacture of Diesel Fuel Injectors

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*The paper deals with details of design and manufacture of parts of fuel-injection pumps, such as plungers and their bushings, and check valves, which must be made with greatest precision in order to permit the injection of an accurately metered amount of oil and to be tight against high pressures. Results of tests to determine the length of bushing necessary to prevent leakage around a plunger are reported and show that this need be much less than is usually specified. The characteristics of materials from which such parts can be manufactured are also given. It is suggested that the parts considered may be easily standardized with benefit to the oil-engine manufacturer.*

THE difficulty in meeting the fuel-injection requirements of the modern high-speed oil engine is ever before the Diesel-engine designer. The need for extreme accuracy in certain parts of the fuel-injection system is keenly realized when it is considered that a four-cylinder four-cycle oil engine rated at 50 hp. at 1200 r.p.m. and consuming 0.5 lb. of fuel per horsepower-hour under full load will require the injection of but 0.00017 lb. of fuel per impulse. This corresponds to approximately 0.0055 cu. in. or 0.0327 cc. The time allowed for completing the injection of this amount of fuel is frequently not more than $^1/_{240}$ of one second. An error in metering of 0.000017 lb. per impulse will cause one cylinder to carry 10 per cent over or under its proper share of the load.

When flexibility of engine performance is considered it is realized that with the engine idling, the indicated brake horsepower would probably not exceed 5 for which the normal fuel charge per impulse would be about 0.000017 lb. and from which a variation of 0.0000017 would represent an error of 10 per cent.

It is readily appreciated that when such exactitude is maintained throughout the entire range of engine performance the problems of the Diesel-engine designer are at least paralleled by those of the artisan who must produce the fuel-injection system.

## Cooperation Between Designers and Builders

In a number of respects it is the author's opinion that designer and builder have been slow to cooperate to their maximum advantage. For example, the author remembers seeing a fuel pump of European design in which four plungers were to be fitted and lapped into four holes in the fuel-pump block as were also the suction and discharge check valves and bypass valves. An accident to one of these fitted holes would therefore mean either scrapping of the entire block or the fitting of an oversize plunger or valve. To make such a block of hardened material would be an economic if not a mechanical impossibility, as would also the making of such a block of stainless or corrosion-resisting material. All three requirements, interchangeable precision parts, sufficient hardness, and resistance to corrosion, are vital to the successful manufacture and marketing of oil engines under conditions now existing in the United States.

In another instance an American manufacturer requested a quotation on lapped valve stems of $^3/_8$ in. diameter, and, in order to make a tight fit against the pressure employed, specified a lapped bushing $6^1/_2$ in. in length. Such an instance would not be cited except that it is typical of Diesel designers to specify a length of lapped fit which is longer and more expensive than is required to secure perfect tightness. This makes the parts more expensive to manufacture than is necessary. Frequently the excessive length of the fitted parts defeats its very purpose through inability to make both hole and plunger perfectly straight and necessitating a poor fit in order to obtain a free motion of the parts.

## Research on Plunger Bushings

The results about to be reported are not presented as an exhaustive research but simply to show

1 That straightness and roundness and a very small difference in diameter allows free mechanical motion;

2 That the length of carefully fitted parts has little to do with their tightness against air pressure or light oils (i.e., kerosene);

3 That it now seems that the length specified for fitted parts to prevent leakage at high pressures need not be greater than that required for mechanical purposes.

To demonstrate these facts the following pieces were prepared (See Fig. 1):

*A* A bushing of hardened steel;
*B* A plug gage;
*C* A plunger;
*D* A second plunger.

The important dimensions of the above are shown in Fig. 1. Checking up the clearances it is found that the difference between the minimum hole (0.87604 in.) and maximum gage (0.87607 in.) shows the gage to have a negative clearance or press fit of 0.00003 in., yet the gage can be wrung through the bushing by hand. The minimum clearance between the bushing and plunger *C* therefore becomes the minimum bushing diameter 0.87604 in. minus the maximum plunger diameter of 0.87608 in., or a clearance of 0.000032 in., while the minimum clearance between the bushing and plunger *D* is 0.000036 in.

It can be seen that either plungers *C* or *D* fit very freely in *A* so long as relative motion is maintained but when the air film which exists between plunger and bushing is destroyed by side pressure, these wring together as would the plane surfaces of two gage blocks.

The inspection test of the author's company for production fuel-pump plungers and bushings designed for delivering lightest oils against highest pressures is that when clean and dry they must be mechanically free to relative movement and when assembled an air pressure of 85 lb. per sq. in. applied at one end while the opposite end is submerged in water at atmospheric pressure, will not produce more than four well-defined bubbles of leakage air per minute.

Plunger *C* with bushing *A* makes an acceptable combination, while plunger *D* with bushing *A* would be rejected. The difference between the maximum diameters of *C* and *D* is only 0.000004 in.

## Effect of Length of Fitted Portions on Leakage

To determine the effect of the length of the fitted portions upon the amount of air leakage, the air-pressure test was performed upon bushing *A* and plunger *C* assembled together but with *C* partially withdrawn from *A*. The point of rejection (four bubbles of leakage air per minute) was not reached until only $1^1/_2$ in. of *C* remained surrounded by *A*.

With reference to the leakage between bushing *A* and plunger *C* when only $1^1/_2$ in. of *C* remains surrounded by *A*, it seems significant that the increase in diameter of *A* coincident with the

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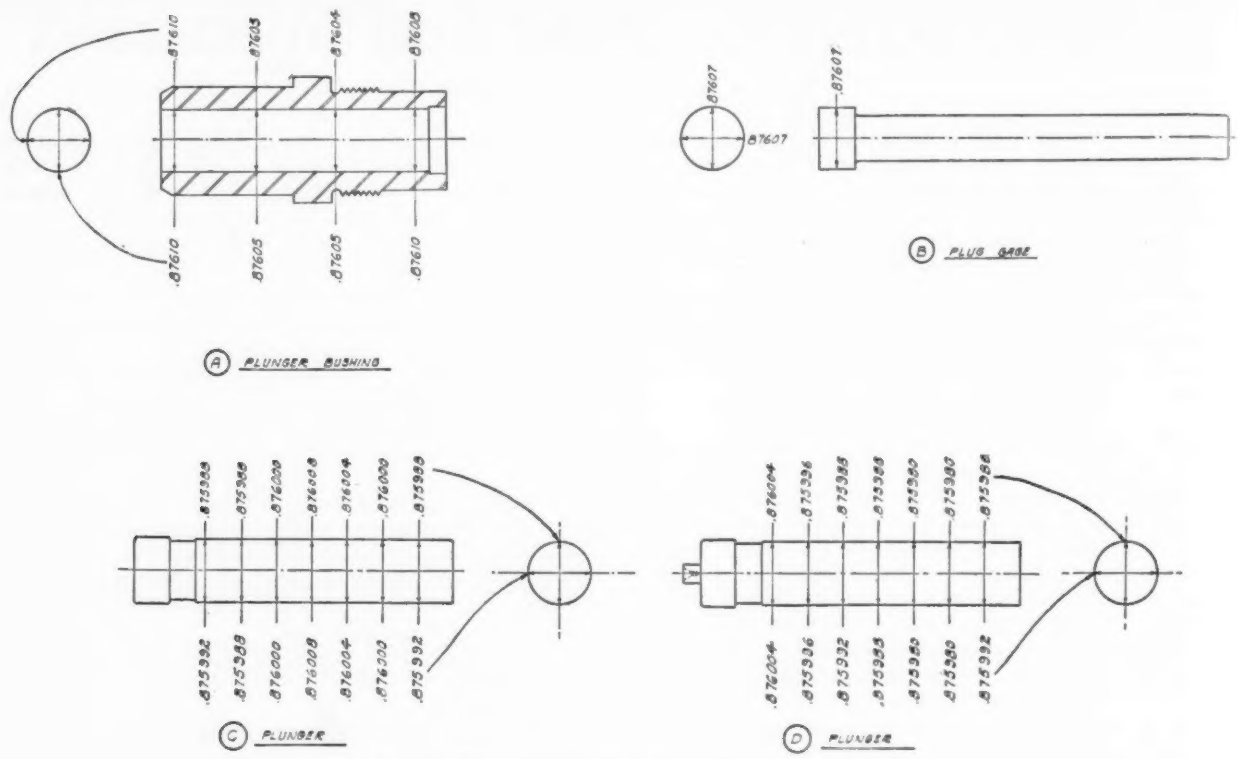


FIG. 1 DIMENSIONS OF TEST PLUNGERS AND BUSHING

decrease in diameter of plunger *C* in its partly withdrawn position increases the minimum clearance to 0.000036 in., under which condition plunger *D* with bushing *A* shows substantially the same leakage. The author is inclined to attribute the increased leakage (of compressed air) to the increased clearance rather than to the decreased length of the telescoped diameters.

It is realized that viscous oils under the circumstances described will perform very differently from compressed air, though not sufficiently differently to warrant attempting to substitute "length of plunger and bushing" for "precision of fitting" as a measure to prevent leakage past fuel-pump plungers.

To determine the relation between rejectable air leakage and the leakage of light oil, *A* and *C* were dried and again assembled in the vertical position with only $1^1/_2$ in. of their lengths coinciding. The volume of *A* not occupied by *C* was filled with kerosene. At the end of thirty minutes standing at atmospheric pressure no leakage whatever was apparent. Air pressure at 85 lb. per sq. in. was then applied on top of the kerosene. At the end of three minutes sufficient kerosene had leaked to form a barely noticeable fillet where *C* entered *A*, but this fillet had not become sufficiently heavy to cause a drop to run down the plunger *C* until 32 min. had elapsed (one hour and two minutes after placing the kerosene and 32 min. after applying a pressure of 85 lb. per sq. in.).

To determine the effect of relative motion (reciprocation) between *A* and *C* with $1^1/_2$ in. of length coinciding and with kerosene at a pressure of 85 lb. per sq. in., plunger *C* was reciprocated in *A* with $^1/_4$-in. strokes at the rate of about 300 per minute. At the end of 1000 strokes the amount of leakage was not noticeably greater than it was when the parts were stationary. The test was discontinued. Observation of similar parts in service indicates that the leakage of fuel oil under operating conditions is not greater than under the continuous pressure mentioned above.

It should here be mentioned that minimum leakage past pump plungers plus perfect mechanical freedom of the parts when cleaned and dried is not the only criterion for successful fuel-pump plungers and bushings as parts exhibiting these satis-

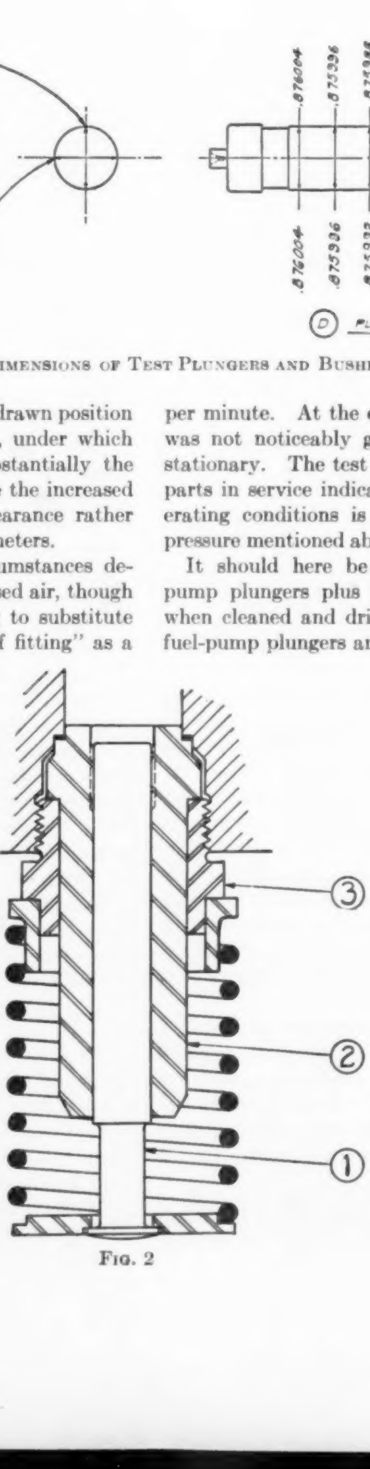


FIG. 2

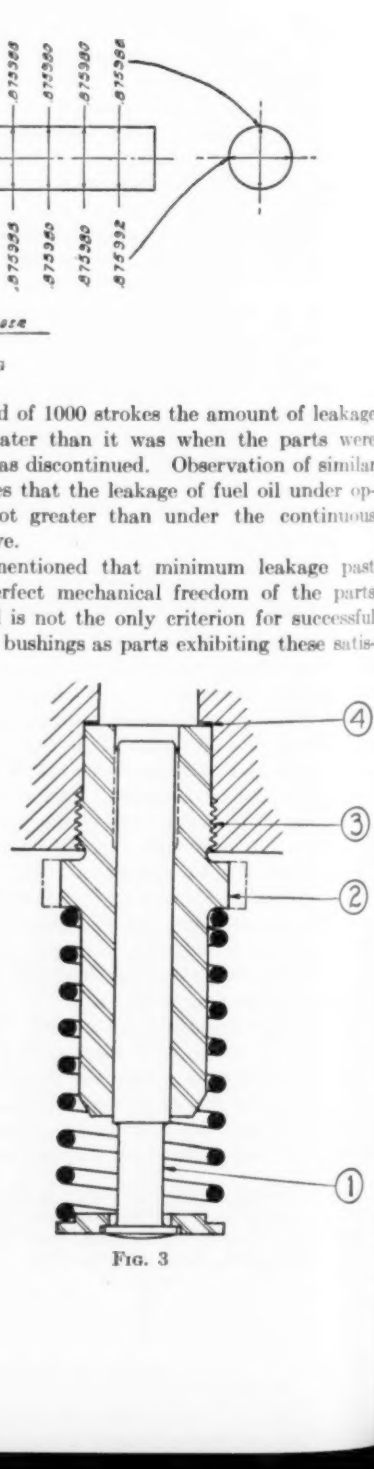


FIG. 3

factory characteristics are not necessarily proof against galling and sticking in service. Sufficient leakage must be allowed to keep the parts bathed with a film of fuel, even though fuel oil has little lubricating value. The clearance must therefore be increased—

1 As the working pressure of the pump is decreased
2 As the stroke of the pump is increased
3 As the speed of the pump is increased
4 As the gravity of the fuel is increased
5 Slightly as the diameter of the plunger is increased.

At some future time sufficient reliable data will have been compiled to permit an equation of the general form

$$C = KH^aG^bD^cP^{-d}$$

to be evolved, in which

$C$ = clearance required between plunger and bushing
$K$ = a constant
$H$ = the product of the length of the stroke by the number of strokes per minute
$G$ = gravity of the fuel oil
$D$ = diameter of the plunger
$P$ = pressure delivered.

### Effect of Design on Cost of Parts and Engine Maintenance

In order that all parts requiring precision workmanship or replacement in service shall be adapted to American manufacturing and servicing methods, it is desirable that the parts, or at least the individual assemblies, shall be interchangeable. The following circumstances make this practice almost imperative:

1 Precision parts such as plunger bushings, valve guides, check valves, injection nozzles, etc. can almost invariably be put on production basis;

2 Frequently by careful standardization the same parts can be made applicable to engines of widely varying sizes;

3 Such parts can be hardened where otherwise impracticable;

4 Such parts can be made of corrosion-resisting material which might not otherwise be feasible;

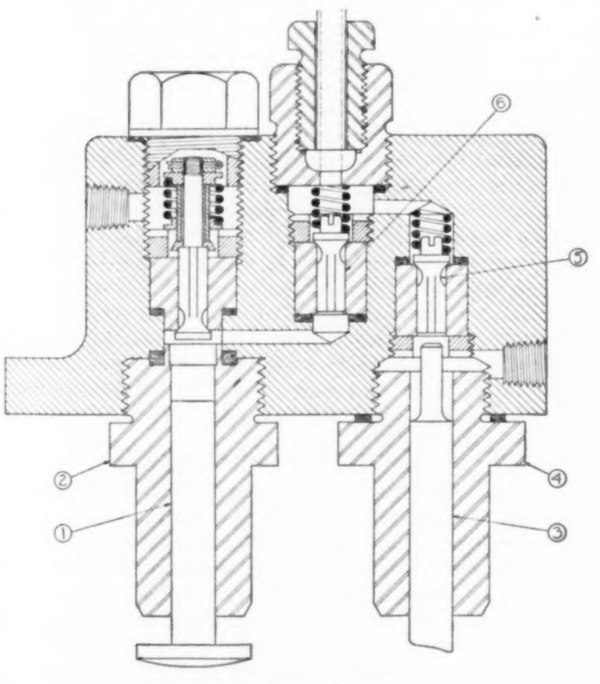


Fig. 4 Check Valves

5 Parts (especially check valves), can be quickly replaced when necessary and overhauled at the operator's convenience;

6 Parts can be tested before installation, minimizing engine shutdown time.

That the design of fuel-injection details has decided effect on difficulties at assembly and in service is shown by the following:

Fig. 2 shows a fuel-pump plunger (1) and fuel-pump-plunger bushing (2) of the design commonly called a collar-mounted plunger bushing, as the bushing is held on its gasket by the pressure of nut (3) on an enlarged diameter or collar which is a part of the plunger bushing.

The advantage of this construction is that proper seating of the plunger bushing on its gasket is less sensitive to inaccuracies in boring the gasket seat and tapping the thread square with the axis of the hole. However, it is important that the plunger bushing should be counterbored or relieved throughout that part of its inside diameter which lies below the lower edge of the collar, shown dotted in Fig. 2, as the setting up of any compressive stress in the plunger bushing after it has once been accurately fitted to the plunger will result in a distortion of the inside diameter of the bushing sufficient to cause the plunger to stick.

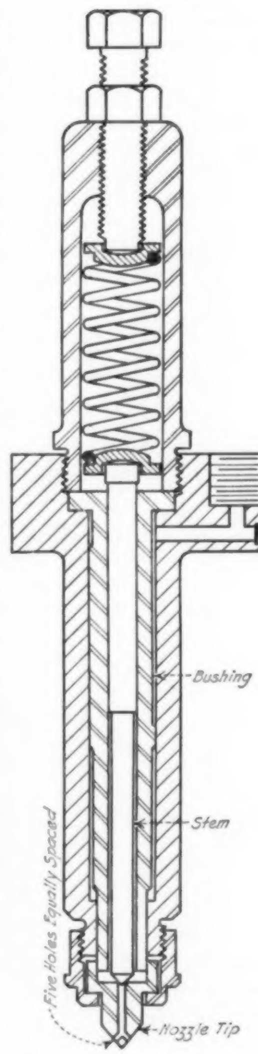


Fig. 5 Spring-Loaded Valve

Fig. 3 shows a portion of a cross-section of another fuel pump of which plunger (1) moves in bushing (2). This is of the threaded type. The advantage of this type is the elimination of the necessity for the nut (3) of Fig. 2. However, care must be exercised in making the axis of the tapped hole in the main pump body (3), Fig. 3, coincide with the axis of the plunger, and in making the pitch diameter of the thread on the plunger bushing (2) substantially under that of the thread in pump body (3), and the gasket seat (4) square with both.

If possible it is also desirable to counterbore or relieve the inside diameter (shown dotted) to avoid placing any of the fitted portion of bushing (2) under compressive or torsional stress. When this cannot be done on account of other conditions, it is necessary to lap plunger (1) and bushing (2) together, while bushing (2) is screwed into a block under conditions similar to those under which it will operate when finally assembled in pump body (4). Even when this is done difficulty may still be experienced unless all threads have been held reasonably square with the gasket seats.

Fig. 4 shows check valves in various combinations as suction valves, discharge valves, back-flow valves, or bypass valves. By making these of hardened steel the seat may be worked at high unit pressures without wear or distortion through hammering. Frequently valves of one given design may serve several pur-

poses in the same pump, thus simplifying the list of replacement parts to be carried in stock.

One commonly used type of bypass or cut-off valve is illustrated in Fig. 4, of which (1) and (2) represent the fuel-pump plunger and its bushings, (5) and (6) represent the suction check valve, while (3) and (4) enable the raising of detail (5) from its seat, thus bypassing any remaining displacement due to the uncompleted stroke of (1), and allowing this discharge to be returned into either the suction channel or a separate bypass channel.

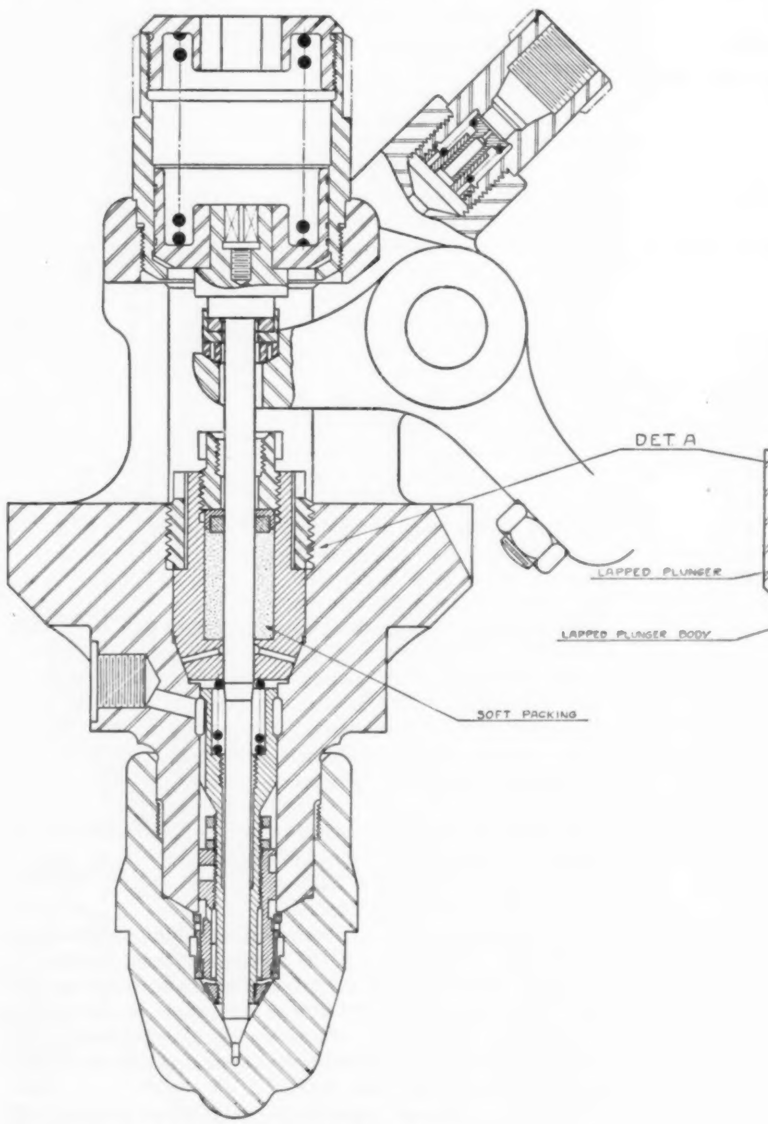


Fig. 6 Air-Injection Fuel Nozzle

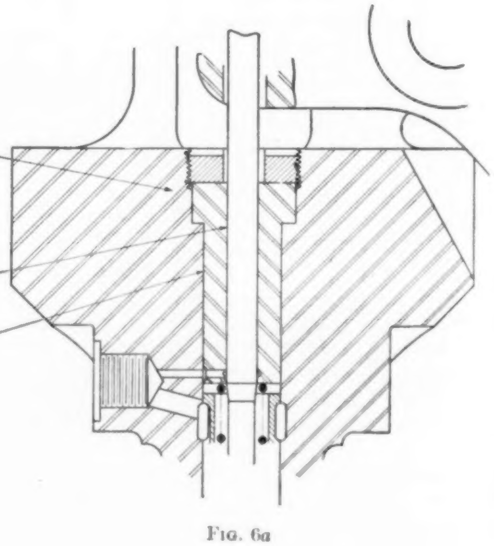

Fig. 6a

Fig. 5 shows a spring-loaded fuel-injection valve, the stem of which is lifted by the hydraulic pressure of the fluid. This valve also involves a lapped stem and bushing with the additional requirements of accurate concentricity and precision fits in order that the nozzle tips may be made interchangeable without the necessity for regrinding the valve seats at each exchange. The drilling of the small holes which often are as small as No. 76 (0.020 in.) is also an operation which calls for special equipment and a considerable degree of skill. Fig. 6 shows an air-injection fuel nozzle for which a suggested redesign has been shown in Fig. 6a. The fuel nozzle in Fig. 6 uses a soft packing, while in Fig. 6a it is redesigned to employ a lapped bushing and plunger. A somewhat similar though not identical application of a lapped valve stem and bushing applied to air-injection fuel nozzles has been in operation for approximately eight months without complaint of any kind and while the manufacturer is not ready to commit himself as to whether such a design should be adopted as standard, the design does have simplicity and freedom from parts that would require frequent replacement or adjustment. As shown at the bottom of Fig. 6a, the fit is lubricated and sealed with the fuel oil, and inasmuch as the pressures encountered are much less than they are in ordinary fuel-pump applications, especially for solid-injection engines, it would seem that this construction might be given consideration by builders of air-injection engines.

## Materials of Construction

It is required that details of fuel pumps be made of materials

that can be worked to the required degree of precision, usually by grinding or lapping processes. The materials after finishing must offer great resistance to wear and preferably exhibit considerable resistance to corrosion.

### Unhardened Tool Steel

Unhardened tool steel takes a beautiful finish, but has come under the suspicion that it is subject to galling. However, in defense of the material, it should be mentioned that at the early date at which this difficulty was encountered, plungers were being fitted more tightly than has later been found necessary to prevent leakage. This material is also subject to the objection that it is actively corrosive in the presence of impurities which are found in many fuel oils.

### Hardened Tool Steel

Hardened tool steel has characteristics similar to those of unhardened steel except that in the hardened state few difficulties with galling have been experienced and these seem traceable to the presence of foreign material such as emery, carborundum, or other abrasives needlessly admitted at assembly.

### Stainless Steels

Many of the stainless steels contain such a high nickel content that it is impossible to harden them. Steels of this character have not been tried for fear that difficulty with galling might be encountered.

Not many brands of corrosion-resisting steel capable of being homogeneously hardened are available. The price seems exorbitant, and the material is machinable only with considerable difficulty. In a standard 20 per cent salt-spray test in which cast iron, tool steel, nitride hardening steel, and hardening stainless steel were present, all samples showed very noticeable corrosion at the end of one hour. However, the sample of stainless hardening steel was less affected than the others, and upon wiping off the corrosion with a 10 per cent muriatic acid solution it was found that the polish on the parts had been barely perceptibly etched, which could not be said of the other samples. Although many thousands of pump parts made from hardened stainless steel have been in service for approximately two years, no reports of any difficulty with corrosion have been received, and the galling by which some parts have failed is believed to have been caused by preventable abrasive dirt.

### Nitride Hardening Steels

A steel known as nitride hardening steel which takes an extremely hard surface when treated at the relatively low temperature of approximately 900 deg. fahr. in the presence of ammonia is understood to have been developed originally by the Krupp interests in Germany. This steel, it is claimed, offers unusually high resistance to corrosion and may, when more universally available and more uniform in quality, become a contender as a material for fuel-pump parts. When properly hardened, it seems to be sufficiently non-corrosive.

### Plunger Bushings

Plunger bushings of ordinary close-grained cast iron have worked satisfactorily, except that special precautions must be taken against allowing them to become charged with the abrasive while lapping. Cast iron also offers no protection against corrosion; and considerable labor may be expended on a part before learning that it is unsuitable on account of porosity. These difficulties argue against the choice of this material. Experimentation is in process with cast iron hardened by various methods and with certain cast-iron alloys in which the density can be increased and some protection from corrosion obtained. These experiments are prompted, however, more by the motive of reducing the cost of the material required than that of obtaining a material having greater freedom from operating difficulties than the hardening corrosion-resistant steel previously mentioned. It is also probable that neither cast iron nor cast-iron alloy will be found suitable for such parts as bypass or check valves on account of the difficulty in obtaining a narrow seat sufficiently free from pores to be certain of freedom from leakage. From the foregoing it is seen that many problems encountered in the field of design, choice of materials, and methods for economically manufacturing interchangeable parts are yet to be solved.

Neglecting entirely the hydraulic phenomena which are a problem of the Diesel designers and confining ourselves strictly to the problems of the Diesel-engine manufacturer, let us give brief attention to the three phases of the problem that has just been outlined.

### Design of Operating Parts Which Must Prevent Leakage Under Hydraulic Pressure

Little is known of the length of lapped or fitted telescoped concentric cylinders required to prevent hydraulic leakage while allowing axial mechanical motion and the variation of this length with the diameter of the plunger or stem; nor of the variation of this length with the pressure under which the parts are to be operated and the variation of length with the grade of fuel to be handled; nor of the effect of the length of stroke upon the clearance between the plunger and the bushing.

Investigation should be made of the precision of fit required under the varying conditions outlined above.

Investigations should be made of methods of mounting or assembling the parts which would permit of the minimum total cost when considering

1 Original cost of manufacture of parts
2 Length of life of the parts
3 Convenience of making service replacement of parts.

Investigation should also be made of the choice of materials which have the necessary resistance to corrosion, resistance to mechanical wear, and freedom from distortion through relieving of internal stresses after the manufacturing operations have been performed. After these requirements have been met it will be necessary to choose materials of minimum cost, having the most favorable machining and processing properties.

### Standardization

The analysis of any number of fuel-injection pumps will show that they consist essentially of certain plungers and bushings, bypass valves, check valves, and other precision parts on which the proper functioning of the pump depends. It is true that the mechanism for operating these parts, the form of the principal parts in which the precision details are mounted, the location and method of driving the pump, etc. will probably always differ widely, as long as oil-engine designers retain their individualities. However there is hardly an oil engine built today which, by the making of certain very simple changes, would not permit the application of standard precision details of the kind which have been under consideration in this paper.

Were these details so standardized, the combined volume of the precision details required as the number of oil engines manufactured continues to increase would uncover a sufficient volume of business to be of interest to manufacturers who are suitably equipped for economically manufacturing these specialities. The resulting competition should insure the Diesel-engine manufacturers of a higher grade of fuel-pump parts at a much lower cost.

## Discussion

R. L. Boyer.[2] Aside from the fuel system, a Diesel engine is essentially a reciprocating machine designed for high pressure. However, the fuel system presents a unique problem. A well-designed injection system can often make a good engine of a poor one, and a poor injection system frequently is the cause of troubles not thought of as being connected with it. The fuel system is really the heart of the engine, whether air- or solid-injection.

With the increased use of sulphur fuels, it has become almost necessary to provide each valve with a removable seat, for frequent grinding to the pump body is necessary, and eventually the body itself must be replaced.

Although the time may never come when all Diesel builders will agree on one design of fuel system there is no reason why individual fuel-pump parts cannot be standardized. Few oil-engine builders are equipped to handle such small and extremely accurate work, and the comparatively small number of these parts to be made does not justify the necessary equipment. The cost of such parts, when standardized, is reduced 50 per cent or more, due to increased volume.

Spare parts, as well as parts for a new pump, can be ordered from the specialist by his drawing number and from his stock room. The specialist can effect research on materials and in other ways in which the engine builder cannot spend so much time. All manufacturers doing business with the specialist would receive the benefits of these investigations, and this is a step toward cooperative research.

W. F. Joachim.[3] The economic aspect involved when each Diesel-engine builder makes all of the specialized engine parts is important as it means an outlay of costly precision-tool equipment and expensive labor without the opportunity for actual quality production. In the automotive industry many of the accessories are constructed by accessory manufacturers, who specialize on and produce such parts as spark plugs, magnetos, carburetors, generators, and starting motors more economically than the car builder. If Mr. Alden will explain how he makes his pump plungers, how the accuracy of the holes in the bushings is insured, state the minimum diameters to which he can operate the internal grinding process, and give the effect of using various steels and heat treatments, I believe it would be of considerable interest. No one has attempted to measure the actual clearance between pump plungers and bushings before, so that a description of how this is done is of interest. The cost of making long tool-steel parts goes up very rapidly with increase in length, and anything that can be done to decrease the actual length of fuel-pump plungers and bushings without increasing the leakage will be economically important. An investigation of the effects of the length and clearance of pump plungers and bushings and of the extent to which they may be varied with the viscosity and pressure of the oil, the amount of movement of the plunger, and the rate of movement should be encouraged, as much valuable data would be obtained.

Some of the methods used by the National Advisory Committee in its experimental pumps may be of interest. The parts are usually made of a high-grade tool steel, the bushing being with a male jig and the plunger with a female jig. The fit is determined by lubricating the plunger and bushing with a high-grade vaseline, attaching a spring scale, pushing the plunger in and pulling it back by means of the spring scale, the amount of force that is registered on the spring scale on the return movement determining the fit. A close-lapped fit requires a 5- to 10-lb. pull with slow relative motion.

We have also used the packed bronze bushing and steel plunger without leakage. Where high pressures have been developed, ranging from 4000 to as high as 15,000 and 16,000 lb. per sq. in., we find that as the injection pressure is increased above 8000 lb. the rate of leakage from this type of plunger increases. The rate of leakage depends upon the thickness of the shell and upon the actual design. If the fuel gets in between the plunger and its bushing at high pressure, it will tend to travel down the clearance space, and if pressure exists between plunger and bushing, it is going to expand the bushing and compress the plunger. If the bushing is thin, it will expand it a great deal. If it is thick, it will expand it; but the large amount of metal around it will prevent measurable external increase in diameter of the bushing and will only permit compressibility of the metal itself. To get around that condition in some of our high-pressure work we have designed a bushing which extends into the high-pressure chamber, the high-pressure joint being made at the outer end of the bushing so that the hydraulic pressure is permitted to flow around the outside of the bushing. We have not varied the shell diameter in such a case, and we have not varied the length of lapped fit, but we have obtained continuous leakproof operation.

In regard to other pump parts, such as the check valves, the Committee has used several of the types shown. The design of the fluted check valve is used by a good many oil-engine companies. We have found that in order to make these valves operate successfully without leakage it is only necessary to construct the width of the seat such that under the hydraulic loads, or the spring loads existing, the pressure between the metal at the seats is from 4 to 10 times the hydraulic pressure.

If there is any fuel between the seats of a pump valve so constructed, the high seat pressures, greatly exceeding the hydraulic pressure, will force the fuel from between the seats rapidly in both directions. The same comment applies to the seats of injection valves in general. In connection with the poppet valve of the type that Mr. Alden showed, and which a good many companies are using, I might state that one of this type has been repeatedly stressed to pressures around 40,000 lb. per sq. in. in an experimental pump and has given successful service without regrinding, relapping, or attention of any kind for the past five years. I feel that standardization of such parts and their manufacture by a company fitted to do that kind of work will be an economic gain to the oil-engine industry.

H. D. Hill.[4] The plea for standardization of fuel-injector parts holds a solution of a vexatious problem. The average engine factory does not include the precision machinery and trained personnel essential to the production of injector parts of the necessary accuracy in sufficient volume to reduce the cost to reasonable limits. Therefore, if standard designs for plungers, bushings, and valves in three or four sizes or enough to cover the field could be adopted, it seems that specialists would find it profitable to supply the demand with greater accuracy and lower cost.

Fig. 2 in Mr. Alden's paper illustrates the type of bushing we advocate, but we favor dropping it into the housing from above and holding it down on a shoulder by means of a threaded plug, which may also secure the discharge valve in a manner similar to that illustrated in Fig. 4. This would avoid ground or gasket joints under pressure between the bushing and housing, simplify the machine operations on the part, and reduce the area of the gasket, which would then rest on top of the bushing. We have made extensive service tests to determine the necessary length of fitted portions of $^7/_{16}$-in.-diameter plungers and bushings and have

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obtained a satisfactory seal of 1500 lb. pressure with 24 deg. B. caloil and an effective length of seal of only $^5/_{64}$ in. at the point of maximum pressure. The length of the stroke used was $^3/_{16}$ in. and the speed 600 strokes per min. Both plunger and bushing were of hardened steel. Our conclusions are that the fitted length is determined by the requirements of safe guiding of the plunger rather than leakage.

D. O. Barrett.[5] I am inclined to disagree with Mr. Alden as to cooperation between the designers of oil-engines and the builders of certain equipment. Mr. Alden seems to feel that oil-engine designers are inclined to design many of the parts so that these cannot be manufactured at a reasonable cost. Many of our spray-nozzle and pump parts have been changed directly, on recommendation of the builders of this type of equipment, much to the engine maker's sorrow. At times it seems that the makers of the smaller equipment are not fully conversant with the problems in oil-engine operation, and are prone to look at them merely from a mechanical standpoint.

Several of our pumps were changed from the design in Fig. 2 to that in Fig. 3, and upon attempting to use the purchased parts we found that these all tightened up at the inner end, making it impossible to move the pump plunger. These were then relieved, as shown, at the upper end with slightly better results, when it was again discovered that it was necessary to screw these bushings very tightly into a dummy corresponding to the fuel pump, thus compressing the metal at the upper end of the bushing, and then lapping in the plunger. This method has given fairly good results, but there is still a question whether the relief at the upper end of the pump plunger should not be eliminated. Any dirt or grit which may come into the pump is prone to settle in this relief, and consequently is drawn down alongside the plunger, scoring it. Were this same material to settle on the top of the plunger bushing without the relief, it would simply be pushed off and would not come directly in contact with the pump plunger.

As to the construction of fuel-pump and spray-nozzle bushings, we have tried out both the hardened and unhardened tool-steel bushings, and in both cases these have galled, and we have now standardized on cast-iron bushings. It is true that cast iron is apt to retain the abrasive material in the pores, but the solution is to secure a metal which shows little porosity. We have had good success in making these up in our own foundry, and bushings which we have cast were of almost as close a grain as unhardened steel bushings. Another point in the fit of the plungers and bushings is the type of fuel to be handled. With one fuel under our observation, unless the plungers are made abnormally loose, when the engine is started in the morning one or more of the plungers which happen to be left in the inner position at night will not return until forcibly pried loose.

The author's company is to be commended upon the experimental work done, but I believe that more consideration should be given the work accomplished by practical oil-engine operators, since upon this depends the success of the parts rather than the purely mechanical construction.

A. W. Morton.[6] There are several pertinent subjects that confront the representatives of the specialty manufacturer at every turn, and I should like to ask the consideration of the engine manufacturers on these three subjects: confidence, cost, replacement.

As to confidence, the agent of the specialty manufacturer can do a great deal for the engine designer or manufacturer if he can gain his confidence. The agent of the specialty maufacturer has an opportunity of travel all over this country and talk to engineers and manufacturers of many different makes of engines, and naturally he will absorb a great deal of information from these various visits. This information may sometimes prove very much worthwhile to the engine designer, and if he would only take the specialty manufacturer into his confidence and tell him his troubles, no doubt he would find that some one else had had similar troubles and how they were overcome. The representative of the specialty manufacturer does not have to tell tales and names at the same time. More frequently than not he has a store of information which would be of the greatest benefit to the engine designer or manufacturer, but he is loath to give this information when it does not seem to be wanted.

If the engine manufacturer is dubious about taking a specialty manufacturer into his confidence, it would then seem advisable for the engine manufacturer to turn to another specialty manufacturer with whom he believes he can safely trust his secrets. It would not be good business for the specialty manufacturer to betray the confidence entrusted to him by an engine manufacturer.

Frequently in my visits around the country I have to call on engineers four and five times before I can even begin to obtain the slightest recognition of friendship. The time taken to break down this barrier of reserve and indifference is time and money lost. Why cannot the engine manufacturer consider the specialty manufacturer more in the light of a friend who is trying to help rather than a competitor who is trying to get some of his business away from him? If the engine manufacturer would make contact with the specialty manufacturer and give him his confidence, it would undoubtedly work to the greatest possible advantage to both.

Cost is a question that needs scarcely to be discussed, for invariably when investigated thoroughly it can be found that the specialty manufacturer can manufacture the same parts very much more cheaply then the engine manufacturer. However, in many cases when the representative of the specialty manufacturer calls upon an engine manufacturer, the general manager or purchasing agent will send for one of his good mechanics, show him the part and say, "What can you make that part for?" The mechanic naturally wants to make a good impression with his boss, and he generally says that he can use such and such an automatic machine and turn out about ten per day. Little consideration does he give to the time taken to set up the machine for this purpose, and also to the fact that the first few lots going through will have to be put through as test pieces and undoubtedly ruined. Finally, when the machine is set up and ready to run, the first lot will invariably be oversize or undersize and will have to be scrapped, and no doubt the second lot will have to be rejected on account of material; and finally the superintendent of the shop will decide to put a more expensive man on the job, and by the time the parts are finally finished they will have cost many times the selling price of the specialty manufacturer's article.

Furthermore, the question of overhead is rarely considered in such cases. If all of these items are taken into consideration, it will be found that the article will not be as satisfactory as could be obtained from the specialty manufacturer, and the cost will be greater.

Replacement is a question that is very frequently overlooked, and is very often feared, but without any just reason. The engine manufacturer is prone to try to keep all of his business in his own shop so that he can control replacements to his own engines. He often feels that he can give better service than can the specialty manufacturer, but in this case he is undoubtedly wrong. The specialty manufacturer has a decided advantage over the engine manufacturer when it comes to replacements, because the specialty manufacturer can invariably adopt standards for the

[5] Chief Engineer, Superior Gas Engine Co., Springfield, Ohio. Mem. A.S.M.E.

[6] Vice-President and Chief Engineer, American Hammered Piston Ring Co., Baltimore, Md.

various parts he has to manufacture, so that many of these parts are interchangeable in various engines. Consequently, by means of this standardization the part can be manufactured more cheaply and a certain stock can be kept by the specialty manufacturer that the engine manufacturer cannot afford to keep, and therefore the question of service is a point decidedly in favor of the specialty manufacturer. Should he not have the exact part in stock, he can invariably set up his machines and make delivery on these parts far more quickly than can the engine manufacturer. In fact, the service performed by the specialty manufacturer can undoubtedly beat the engine manufacturer in every conceivable way.

The engine manufacturer often considers that the specialty manufacturer will take a lot of replacement business away from him which should by right come to the manufacturer of the engine. In this connection, do you think that the specialty manufacturer is willing to jeopardize the business of the engine manufactures in order to get some of the replacement business on any particular engine? I personally think the fear that the engine manufacturer has of the specialty manufacturer's getting his replacement business is unfounded. The specialty manufacturer naturally wants to get this replacement business, but preferably through the engine manufacturer, so that he cannot only hold the entire business of the engine manufacturer, but also help him to get more replacement business by giving better service.

A decided step in advance will have been made if the specialty manufacturer and the engine manufacturer will get together and talk over these problems and decide between them how they can help each other keep the replacement business where it belongs, namely, to the engine manufacturer; and then in turn the engine manufacturer will give it to the replacement manufacturer.

It is only by this cooperation between the engine manufacturer and the specialty manufacturer that this barrier of distrust can be broken down, and then both the engine and the specialty manufacturer will profit to the greatest advantage.

C. E. Beck.[7] I am interested in this subject because my time is engaged in the sale of Diesel engines, and if we can adopt some standardization of parts which will reduce manufacturing costs and thus overcome the argument that costs are too high, we naturally can sell more engines and thus increase production with a still further reduction of manufacturing costs. In some of the air-injection engines first installed in the West, corrosion, erosion, and wear of the fuel needles became manifest, and more especially on crude-oil pipe-line installations. Our former discussion on standardization of fuel oil applies to the country in general, but in pipe-line work Diesel engines consume a good deal of raw crude, taking it directly from the pipe line. Many of the crude oils contain acid, which manifests itself in the engine by corroding and pitting the fuel needles and the fuel-pump plungers and valves. Water in the fuel oil and in the injection air has an eroding effect upon fuel needles, sometimes tearing them off much the same as wet steam tears away the buckets or blading in a steam turbine. Water in the injection air has been largely eliminated by the use of intercoolers and aftercoolers of efficient design, although a careless operator may be negligent and not blow them out with sufficient regularity to prevent a few occasional globules of water from going through to the fuel valve. I visit many Diesel-engine plants each year and see the parts that become broken, worn, corroded, etc. Therefore, to manufacture fuel-pump and fuel-valve parts for air-injection engines, a material that will resist wear, corrosion, and erosion must be employed. We had rather good luck with cast iron originally, but later secured best results from cast-iron alloys.

[7] Busch-Sulzer Bros.-Diesel Engine Co., St. Louis, Mo.

# European Diesel-Engine Developments

## An Illustrated and Historical Account of Progress in Diesel-Engine Design and Application in Europe

By OLIVER F. ALLEN,[1] SCHENECTADY, N. Y.

WHEN I agreed to present this summary of the oil-engine situation outside of the United States, I did not realize the magnitude of the mass of data which would be available and I now find myself confronted with the embarrassing task of keeping this paper within reasonable limits and at the same time giving typical illustrations and figures presenting a reasonably clear picture of what is going on abroad without unduly emphasizing any particular type of engine or the products of any one shop or country.

Out of several hundred excellent pictures I have made a selection[2] which should be indicative of what our foreign friends are doing and I shall give a few data for the same purpose.

The growth of oil-engine manufacture has been so vast in Great Britain and on the Continent that I cannot possibly include reference to many important and interesting developments. I have time to mention only a few manufacturers and their products. I have tried to select those which are typical. I am sure that others, faced with this same task, would have made a different selection. If some familiar type or make has been omitted or only touched upon, please remember that I am only trying to sketch a general view of the industry abroad and have naturally used the materials which happen to have been available.

And here let me express publicly our great obligation to the officials and engineers of the oil-engine builders in Switzerland, Germany, Italy, France, Belgium, Holland, Sweden, Denmark, England, and other places for their courteous and generous response in sending data of what they are doing. I only regret that there is not time to give more details, for they are all instructive and interesting.

This paper will review briefly the history of the Diesel motor. It will then refer to the growth of the industry and touch upon what has been accomplished with solid injection, including automotive work, and with supercharging. The development of the double-acting engine will be described, and finally the latest tendencies in power station and marine applications will be referred to.

### Historical Sketch

Dr. Rudolf Diesel secured his first patent in February, 1892, in Germany, followed by another in 1893. The exploitation was initiated by the Maschinenfabrik Augsburg, now commonly called the M.A.N. Licenses were granted in 1893 to M.A.N. and Krupp in Germany, and to Sulzer Bros. in Switzerland.

The next contract was with Carels Frères of Ghent, Belgium, early in 1894. Under this license Carels completed a single-cylinder engine in August, 1894. Fig. 1 shows this engine, and is from a photograph, bearing the endorsements and stamps, which was registered for Belgian patent purposes.

Sulzer's first engine was produced in 1896.

The year 1894 is within the memory of most us. The thirty-four years that have passed are only the normal span of a generation and yet this great oil-engine industry has developed in this short period.

In 1898 the Diesel engine syndicate was formed, called the Allgemeine Gesellschaft für Diesel Motoren, followed soon by the Diesel Engine Company of England. The export of German, Swiss, and Belgian engines began about this time. Mr. Adolphus Busch purchased the United States and Canadian rights in October, 1897, and the first American Diesel, a 60-b.hp., 2-cylinder engine, was completed in September, 1898, by what is now the Busch-Sulzer Bros.-Diesel Engine Co.

Fig. 1 First Diesel Engine Built by Carels Frères, Ghent, Belgium, in 1894

Burmeister & Wain, of Copenhagen, Denmark, with long shipbuilding and marine-steam-engine experience, took a Diesel license in 1898 and produced their first engine in 1902.

Atlas of Stockholm started their Diesel engine works in 1898 and produced two-cycle, direct reversing marine engines in 1907.

[1] Manager, Automotive Sales, International General Electric Co., Inc. Mem. A.S.M.E.

[2] Colonel Allen showed many more pictures in the presentation of his paper than it has been found practicable to reproduce.—Editor.

Presented at the National Oil and Gas Power Meeting, State College, Pa., June 14 to 16, 1928, under the auspices of the A.S.M.E. Oil and Gas Power Division, The Pennsylvania State College coöperating.

Werkspoor of Amsterdam, Holland, took a license from M.A.N. in 1902 and built their first seagoing engine in 1908.

The development of commercial engines suitable for industrial plants required about nine years, and in 1902 what might be considered reliable standard engines were built in Europe and in the United States. At least one produced that year is still in running order and was in regular service until the fall of 1914.

In 1905 there was an exhibition at Liége, Belgium, at which a Carels 3-cylinder, 500-b.hp. engine was shown as the largest Diesel engine which had been built up to that time. Its generator was direct-connected.

By 1909 Schneider, the great French ordnance firm at Le Creusot, had taken a Carels license and as they wished to build larger engines than then existed, the Ghent works made in 1910 a 1000-b.hp. single-cylinder, 2-cycle, single-acting engine 820 × 1000 mm. ($32^1/_4$ × $39^1/_2$ in.), at 150 r.p.m. This engine developed full output on the test block at Le Creusot but smoked some. So far as I know, this was the first 1000-hp. cylinder built anywhere.

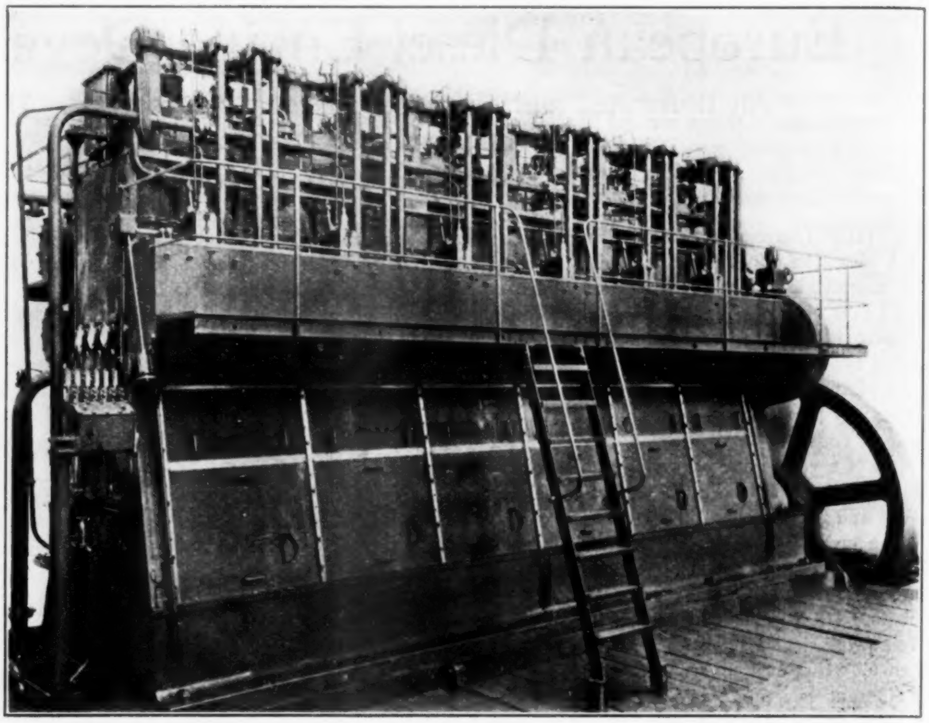


Fig. 2 M.A.N. Airless-Injection Diesel Engine, 6-Cylinder, 4-Stroke Cycle, 1575 B.Hp. at 187 R.P.M.

Vickers took a Carels license in 1910 and these two, Schneider in France and Vickers in England, started the development of Diesels for naval service which has since become so important.

Between 1900 and 1914 many licenses were granted by Sulzer, M.A.N., Carels, and others of the original builders.

The Phelps-Dodge Corporation bought two 1150-b.hp. Carels engines in 1913 for their Douglas, Arizona, plant. These are believed to have been the largest oil engines in the United States, when they were started in 1914. The Nordberg license followed and the large Diesel plants of the Phelps-Dodge properties resulted.

Before the World War interchange of engineering data and grouping of manufacturing interests in order to give to the public the best possible product, to the workman steady employment at fair wages, and to every market, all over the world, the product at the lowest prices consistent with these requirements, was unusual. It is now common practice and is being profitably applied in oil-engine manufacture by several important international groups. Not only is this growth of engineering cooperation among the nationals of the leading powers accelerating improvements and reducing costs to the ultimate user, but the personal contacts involved are a mighty powerful influence toward World Peace.

It is a great pleasure to be able to emphasize how really international this movement is, and to know that the United States, Japan, England, and the Continental countries are all among those contributing.

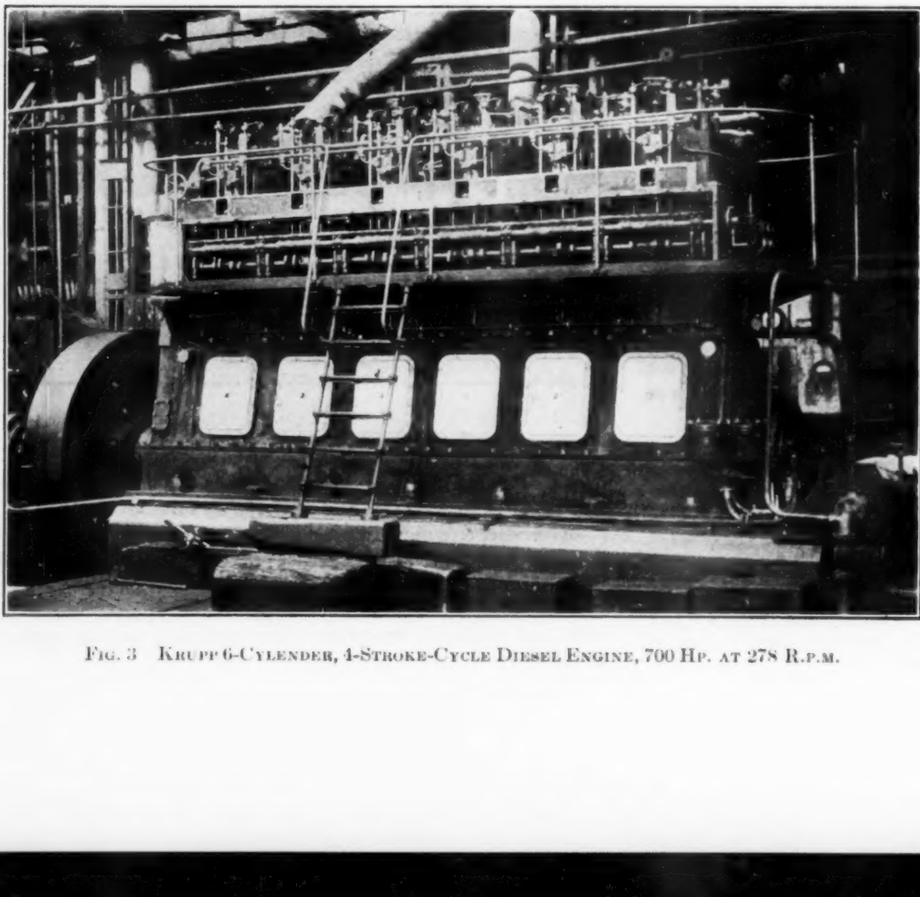


Fig. 3 Krupp 6-Cylinder, 4-Stroke-Cycle Diesel Engine, 700 Hp. at 278 R.P.M.

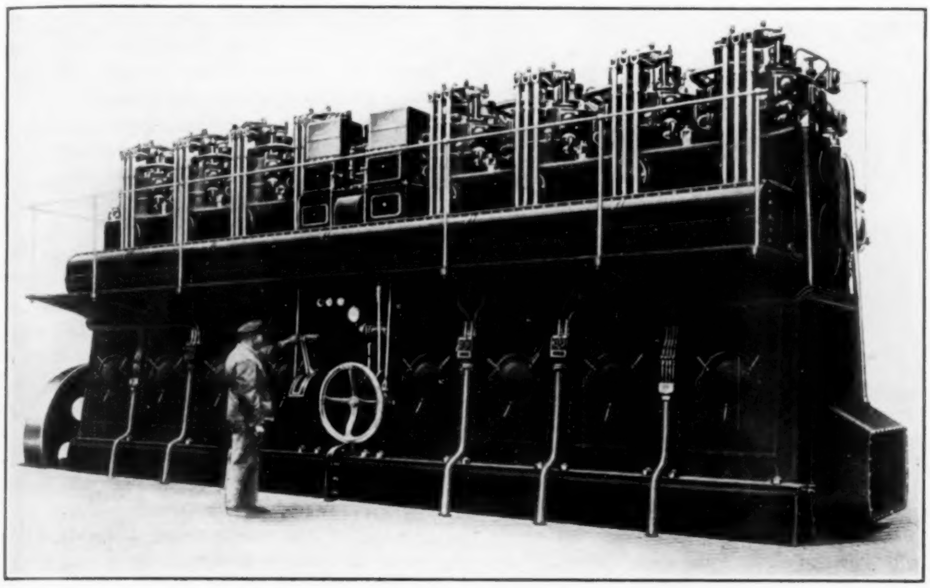


FIG. 4 DEUTZ 1200-HP. SOLID-INJECTION DIESEL ENGINE

Another shop which is producing large oil engines on an extensive scale is that of the A.E.G. at Berlin.

Space limits the mention of many other important plants such as Mitsubishi in Japan, Tosi in Italy, and the State Engineering Works in Moscow.

The greatest expansion of the industry has been in marine propulsion with such concerns as Harland & Wolff and Doxford in England, as well as several of those already mentioned, taking a leading position. According to the English *Motor Ship* of May, 1928, on April 1 of this year there was 1,333,875 i.hp. of marine Diesel engines building. This is about 100,000 i.hp. more than at the end of 1927. For over a year now both gross tonnage and horsepower of motorships under construction have continuously exceeded the total of reciprocating and turbine steamships combined.

It has been my good fortune to be intimately associated with this engineering and manufacturing international liaison work during the last ten years and I assure you it is sincere, earnest, and constructive. The generous responses of our foreign friends with data for this address is a concrete evidence of it.

Dr. Diesel was an outstanding example of the practicability of international cooperation. He consulted freely and frankly with the engineers of the many licensees in Germany, England, Belgium, and elsewhere and saw all their improvements without abusing their confidence or divulging their secrets, always helping all of them to advance the art.

## GROWTH OF THE INDUSTRY

In the quarter of a century since the Diesel engine became commerical a great industry has sprung up. One of the largest oil-engine works is Burmeister & Wain's at Copenhagen, employing 8000 men. Their developments have been chiefly in the marine field. There are one million horsepower of their engines afloat and over half a million building. They have engined nearly 300 ships of over 2000 gross tons, all with 4-cycle engines.

The M.A.N. works at Augsburg also employ a large number of men and have produced engines of 15,000 b.hp. on a single shaft.

The Sulzer Works, at Winterthur, Switzerland, with their licensees have built more than two and a half million horsepower of Diesel engines for stationary plants, for more than 300 ships, and for locomotives and railcars. Sulzer Bros. employ 4100 men and during 1927 they received orders for about 230,000 i.hp. to which should be added about 160,000 i.hp. ordered from licensees, making a total of 390,000 i.hp. of Sulzer engines sold last year. Their erecting shop is a busy place.

A typical smaller plant is the Carels Works at Ghent, Belgium, where slightly more than 1200 men are employed on Diesel-engine production. Mass production methods are employed on large parts.

## AIRLESS FUEL INJECTION

This brings us to the consideration of types and special features. We shall first consider the solid-injection or, as it is called

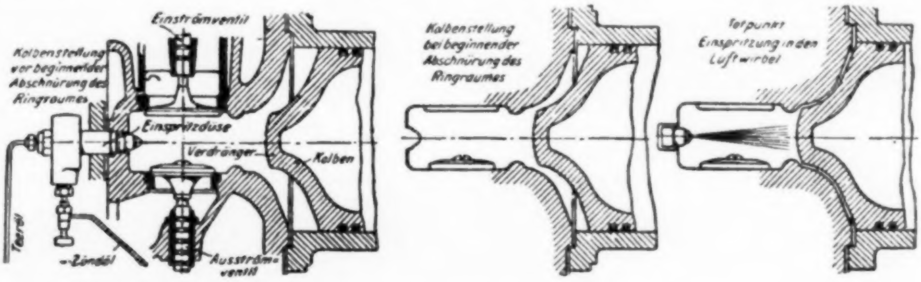



FIG. 5 PRECOMBUSTION CHAMBER OF DEUTZ DIESEL ENGINE

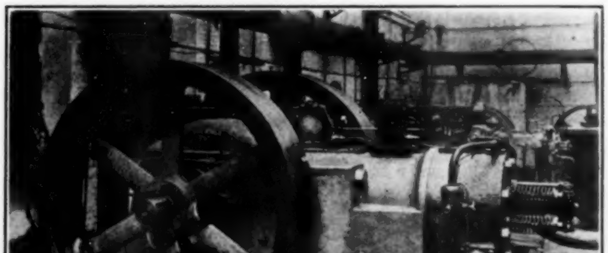


FIG. 6 DIESEL ENGINE OF INGERSOLL-RAND DESIGN BUILT BY CARELS

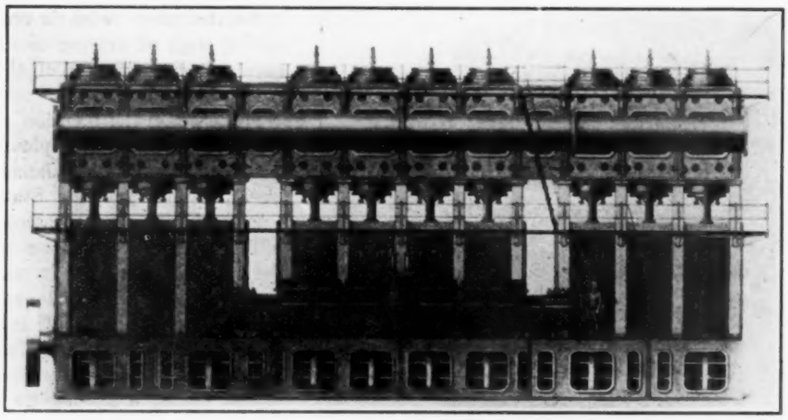


FIG. 7 A.E.G.-HESSELMAN DOUBLE-ACTING TWO-STROKE-CYCLE ENGINE, 1500 B.HP. AT 120 R.P.M.

abroad, airless-injection, and in England, cold-starting type.

The airless-injection type is an outcome of the desire to improve the performance of the hot-bulb type and at the same time avoid the complications of the air-injection type. It is practically a development of the last five years and seems to have been initiated in England, although so many engineers were working on the problem in several countries directly after the War that it is perhaps unfair to give any one group especial credit. It was well established in engines up to about 750 b.hp. some four years ago and is now employed in engines up to 11,700 b.hp. and proposed for some up to 15,000 b.hp.

M.A.N. have built airless-injection engines in a wide range of sizes. Fig. 2 shows one of their 6-cylinder, 4-stroke-cycle engines developing 1575 b.hp. at 187 r.p.m.

Another German manufacturer, Krupp at Essen, has built solid-injection engines. Fig. 3 shows a 6-cylinder, 700-hp., 4-stroke-cycle, 275-r.p.m. engine of their manufacture.

Fig. 4 shows a typical solid-injection 1200-hp. engine built by Deutz of Cologne, Germany. Deutz were one of the first to employ solid injection and in their early horizontal engines introduced a precombustion chamber as shown in Fig. 5.

The cylinder space is practically closed when the conical piston head reaches the annular neck in the cylinder cover, leaving the small precombustion chamber between the inlet and exhaust valves as the space into which the fuel is injected. It is interesting to note from the left end of the diagram that this type of engine is applicable to the use of tar oil (teeröl), with light oil (zündöl) for starting and partial-load service. A similar injection-pump arrangement for mixing heavy and light oils at the point of injection is employed by Carels, Sulzer, and others to permit using the cheap, bad, heavy oils, such as Panuco crude, and Bunker "C," in large engines.

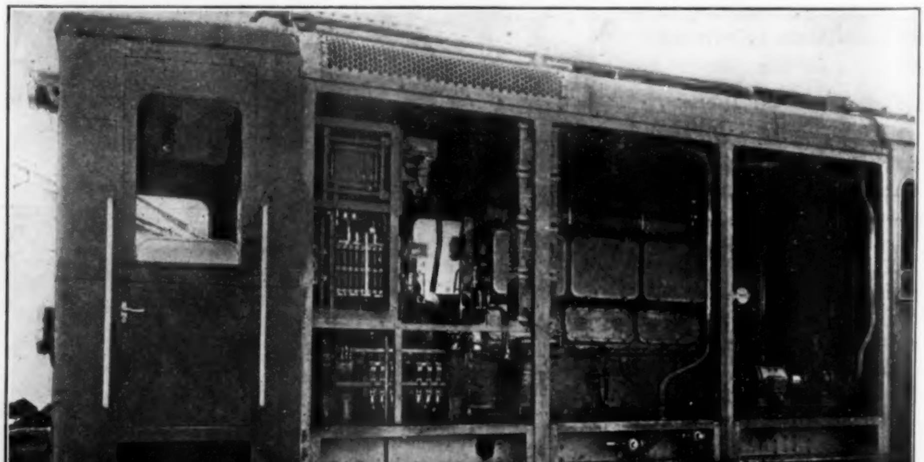


FIG. 9 ENGINE ROOM OF RAILCAR FITTED WITH A FIAT DIESEL ENGINE

Deutz subsequently developed the semi-spherical hollowed-out piston head and abandoned the precombustion chamber for their larger vertical solid-injection engines, of which they have built approximately 50,000 hp. in sizes up to 1350 hp. in 8 cylinders at 190 r.p.m. For their automotive type of engine, which will be referred to later, they have reverted to the precombustion chamber design.

As an example of international cooperation, Fig. 6 shows a single-cylinder horizontal engine being produced on a large scale in Belgium. It is a Chinese copy of the Ingersoll-Rand Company's Price engines designed and built in the United States.

In Europe and in many neutral markets the cost of gasoline is so much more than that of Diesel oil or gas oil, as it is frequently called, that small contractors' engines are solid-injection oil engines, although they may be very small.

Extensive use is made of the medium-size airless-injection engines for auxiliaries on ships and in power plants.

Fig. 7, which is a design for a 15,000 b.hp. double-acting, two-stroke-cycle, A.E.G.-Hesselman airless-injection engine, shows

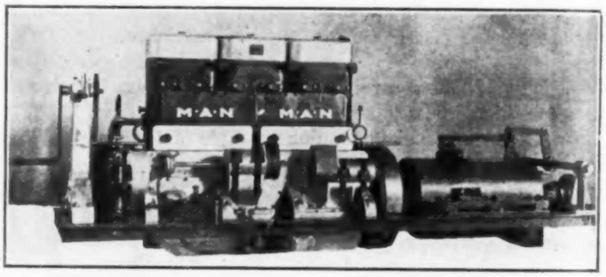



FIG. 8 M.A.N. AUTOMOTIVE ENGINE, 60 B.HP. AT 900 R.P.M.

to what sizes the solid-injection system is being applied. The M.A.N. are now building some 11,700-b.hp. engines of the solid-injection type.

The large Still engines of England, to which I shall refer later, also employ this type of fuel injection.

FIG. 10 RAILCAR OF THE SWISS FEDERAL RAILWAYS, WITH SULZER 300-B.HP., 4-CYCLE DIESEL ENGINE

## AUTOMOTIVE APPLICATIONS

While airless injection has been extended to these very large sizes, the automotive type of engine has been developed. The M.A.N. development, now utilized by Buda in this country, is fairly familiar. Fig. 8 shows one of the German-built 60-b.hp., 900-r.p.m. egines. In England and on the Continent, Diesel engines are already used for automotive work, including trucks, tractors, railcars, and locomotives.

Fig. 9 shows the power plant of a railcar recently tested on the Italian State Railways. The engine is built by Fiat in Italy

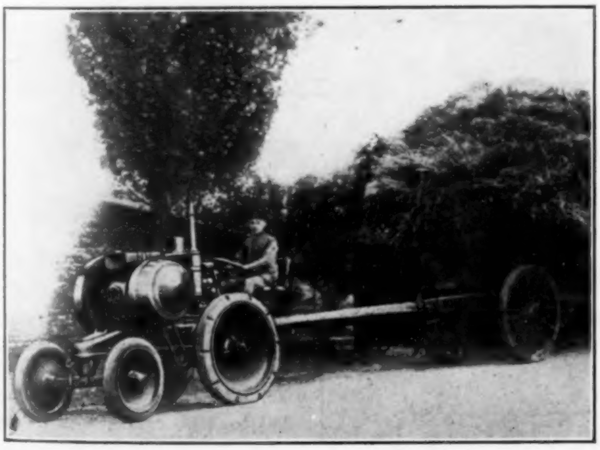


FIG. 11 DEUTZ ROAD TRACTOR

and is rated at 200 b.hp. Electric drive with direct-connected generator and ordinary traction motors is employed. Fiat also makes an engine with a normal rating of 150 b.hp., 170 b.hp. maximum, at 1200 r.p.m., which weighs with flywheel but without bedplate for supporting engine and generator only about 26 lb. per b.hp. normal rating.

Fig. 10 shows a railcar on the Swiss Federal Railways with a Sulzer airless-injection engine, rated at 300 b.hp. at 550 r.p.m. The power plant is in the center of the car and electric drive is used. The engine, with bedplate and accessories, such as fuel tank and cooling fan, weighs about 44 lb. per b.hp. Electric starting is also employed for this engine. This car has two bogie trucks, each with one motor axle and one driving axle. The length over buffers is 66 ft. 7 in. and between center pins, 44 ft. The drawbar pull at starting is 10,120 lb. and the maximum speed $37^{1}/_{2}$ m.p.h. The shop tests of the engine with fuel oil of 18,000 b.t.u. per lb. showed full-load consumption of 0.418 lb. per b.hp-hr. The trials were in February, 1928, over a 92-mile run with a trailer weighing 18 tons. The total train weight was 75 metric tons and the fuel consumption 0.0235 lb. per ton-mile.

Sulzer are now building Diesel locomotive power plants with this type of electric transmission up to 2500 hp.

Deutz, at Cologne, have brought out several models of automotive machines, all with solid-injection oil engines, such as tractors and locomotives, all with mechanical drive. Fig. 11 shows the road tractor in service and replacing horses.

Figs. 12 and 13 show the Deutz automobile Diesel engine which is said to use any fuel offered on the market. The small cylinders of this engine have precombustion chambers to aid in the burning of heavy oils as previously described. The cylinders are

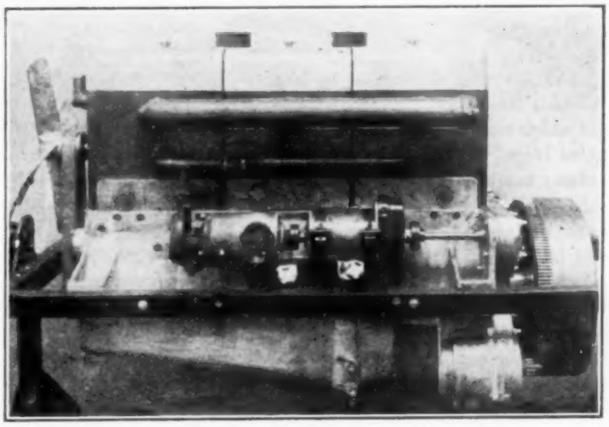


FIG. 12 DEUTZ AUTOMOBILE DIESEL ENGINE

cast in blocks of two. The 4-cylinder automobile model develops 40 hp. and weighs 39.6 lb. per hp. The 6-cylinder engine develops 60 hp. and weighs 34.5 lb. per hp. Both run at 1000 r.p.m.

Another railroad application was described in *Oil Engine Power* for April, 1928. This is a locomotive with a 250-b.hp. engine built by the Cie de Construction Mécanique Procédés

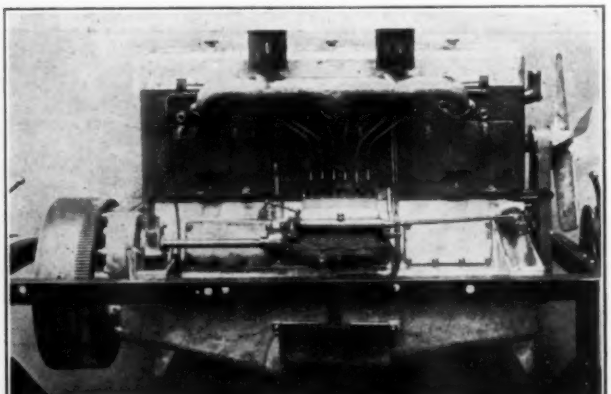


FIG. 13 DEUTZ AUTOMOBILE DIESEL ENGINE

Sulzer, Paris, with electric drive. This locomotive with about 80 tons trailing showed a gas-oil fuel consumption of from 0.024 to 0.043 lb. per ton-mile of total train weight according to grades,

loads, speed, and road conditions on the various divisions of the Tunisian Railways on which the train has been used.

The same issue of *Oil Engine Power* describes a new Junker's two-cylinder opposed-piston 45/65-b.hp., 1000/1500-r.p.m. automotive engine. This engine without flywheel weighs only 610 lb. or 13.6 lb. per b.hp. at the 45-hp. rating and only 9.5 lb. at the 65-hp. rating.

An interesting English development is the 500-b.hp. oil-electric train for the London, Midland and Scottish Railway of England, developed by William Beardmore & Co., Ltd., and the English Electric Co., Ltd.

The train, consisting of motor coach and three trail cars, accommodates 32 first-class and 255 third-class passengers. Empty, the train weighs 144 long tons. This means about 165 tons including passengers and baggage. The engine has eight $8^1/_2 \times 12$-in. cylinders and develops 500 b.hp. at 900 r.p.m. It weighs $14^1/_2$ lb. per b.hp. There is double-end control so that the driver can regulate the engine speed as well as manipulate the electrical controls from either end of the train. This train made its trial runs recently between Blackpool and Manchester and has been put into service on a short run out of Blackpool.

Diesel-electric railcars have been in regular service on the Swedish Railways since September, 1913. Half a dozen are in use which were started before the end of 1917. The Aktiebolaget Atlas Diesel of Stockholm have supplied about 50 oil engines for railway traction service, the majority with electric drive made by the A.S.E.A. (Swedish General Electric Co.). These engines range in size from 4-cylinder, 60 b.hp. at 600 r.p.m. to 12-cylinder, 300 b.hp. at 550 r.p.m. and are all of the 4-stroke-cycle air-injection type. Fig. 14 shows the 300-b.hp. engine and Fig. 15 the 150-b.hp. 6-cylinder engine installed in a Diesel-electric car.

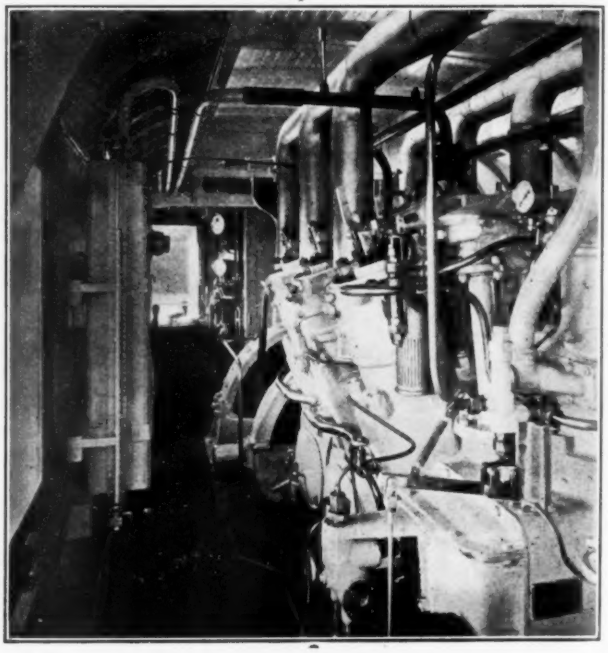


Fig. 15 150-Hp. 6-Cylinder Diesel Engine Installed in Railcars

While the engines just shown are all of the air-injection type, the Swedish Atlas have recently developed and sold several solid-injection engines for rail service. The new type is also 4-stroke cycle and so far is being made in four ratings, 4-, 6-, and 8-cylinder, 80, 120, and 160 b.hp. at 875 r.p.m. and 6-cylinder 250 b.hp. at 550 r.p.m. Krupp at Essen have developed a 100-hp. 1000-r.p.m. automotive engine weighing 1500 lb. as shown in Fig. 16, weighing 15 lb. per hp.

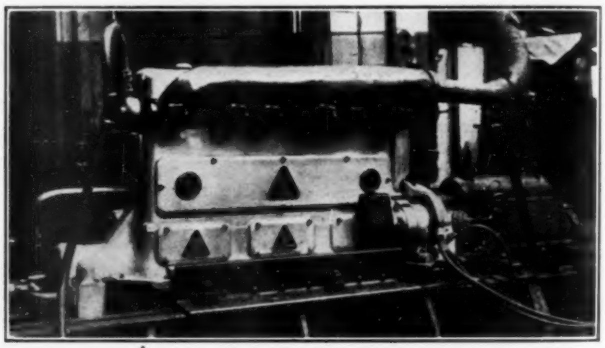


Fig. 16 Krupp 100-Hp. 1000-R.p.m. Automotive Engine Weighing 1500 Lb.

The illustrations of automotive engines, which have been mentioned were built by leading manufactures in five countries with a range of weight of from 9.5 lb. per b.hp. net for the engine alone to 44 lb. per b.hp. including some auxiliaries, with from 15 to 30 lb. for engine with normal equipment, predominating. The range of sizes is from 40 to 500 b.hp. and of speeds from 550 to 1500 r.p.m. with about 1000 r.p.m. predominating. There are several other makes, say at least a dozen outside the United States. It is therefore reasonable to say that the automotive, airless-injection Diesel engine in sizes up to 500 b.hp. weighing not over 30 lb. per b.hp. with a speed of about 1000 r.p.m. has arrived and that we can anticipate that reliable engines of half that weight at 1200 to 1500 r.p.m. will very soon be available from several manufacturers in five or six countries besides the United States.

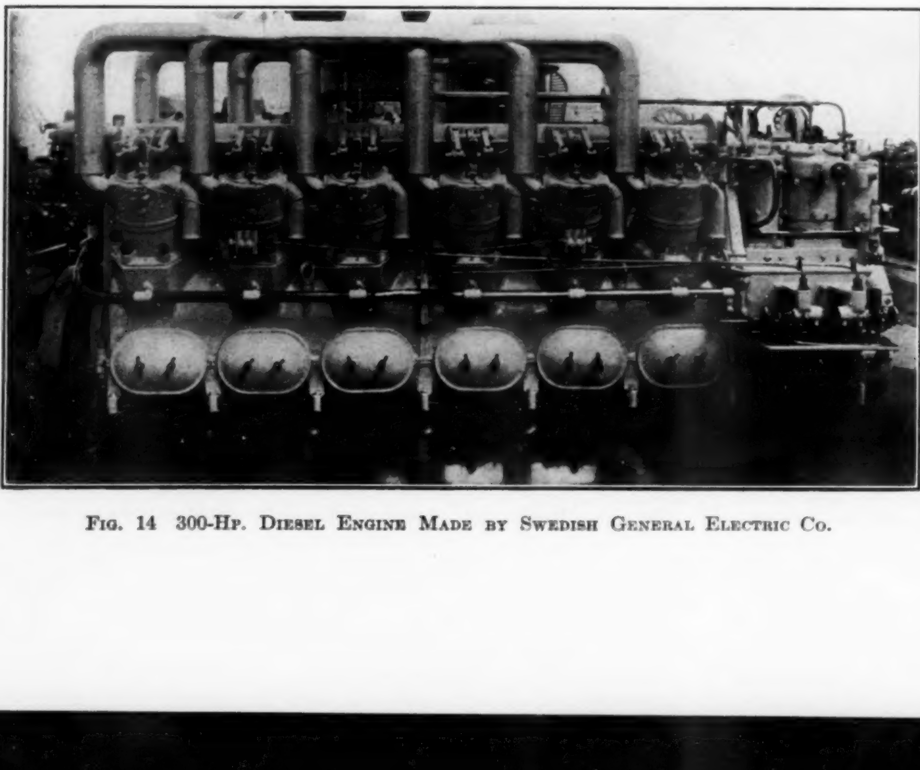


Fig. 14 300-Hp. Diesel Engine Made by Swedish General Electric Co.

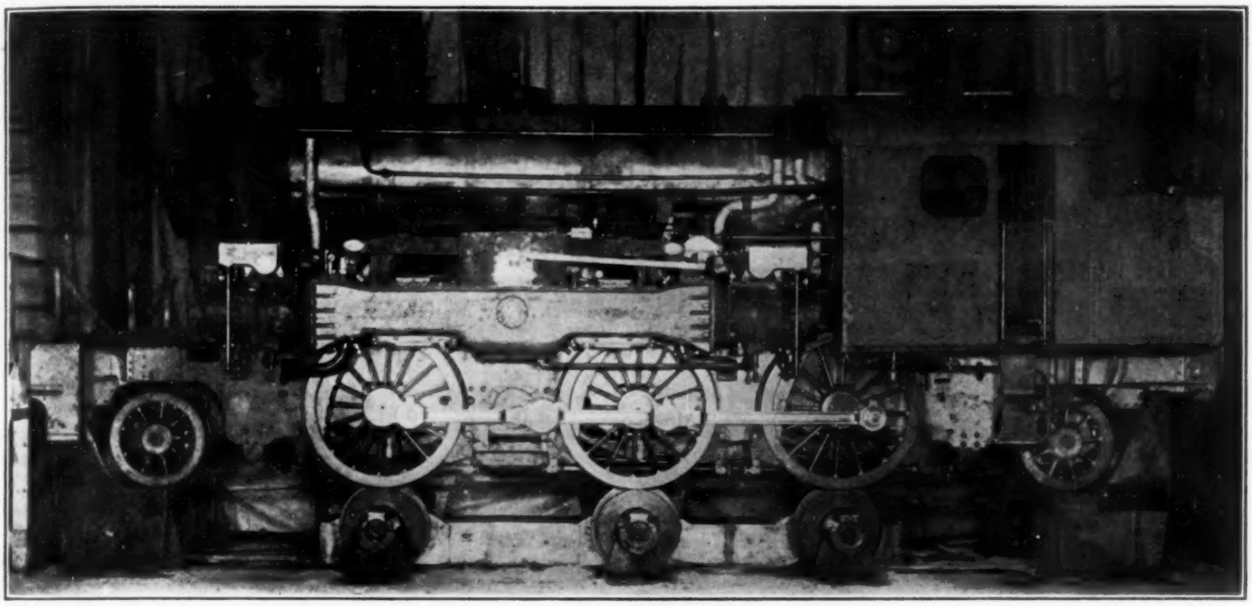


Fig. 17 Kitson-Still Oil-Steam Locomotive

With engines weighing 15 lb. per b.hp. at a speed of 1200 to 1500 r.p.m. the electric-drive Diesel locomotive and railcar have a very large field all over the world as the relation of weight of power plant to its supporting structure and to the weight of trailing load will permit the horsepower per ton required for efficient railway service.

An interesting development has been the Still engine in England. Fig. 17 shows the new Kitson-Still oil-steam locomotive, direct-coupled, with gear side-rod combination drive built by Kitson & Co., Ltd., Leeds. This locomotive weighs 85 long tons with $19^1/_2$ tons on each of three driving axles. The engine has 8 cylinders $13^1/_2 \times 15^1/_2$ in. and operates on the 4-stroke cycle at 450 r.p.m. At 45 m.p.h. the drawbar pull is 7000 lb. During the last four months it has made several trial runs with as much as 118 tons trailing over a 31-mile triangular loop.

All of the automotive engines referred to, including the Still and the new Atlas design, employ airless injection. While the methods and pressures employed in injecting, atomizing, and controlling the charge when air injection is employed are pretty well standardized, the pressures, method of control, and arrangement of pumps vary widely in the solid-injection engines. Injection pressures vary from 1000 to 5000 lb. per sq. in. Some manufacturers, as, for instance, Deutz and M.A.N., use individual pumps for each cylinder but with different pressures. Ruston of England has recently changed to a single pump and a distributor, athough of a different type from that employed by the Carels-Ingersoll-Rand group. A.E.G.-Heselman use individual pumps with suction-valve control. Others use a single pump with a high-pressure manifold and control by timing the opening of the injection valves. It is too early in this development to tell which combinations will survive but more accurate timing and quick, positive cut-off of the injection oil stream combined with improved spraying action during injection of the fuel oil seem to indicate the direction in which research is tending.

The trend of foreign rail transportation development, especially for narrow gage, for lines with infrequent service, and for industrial works, certainly seems to be toward the Diesel

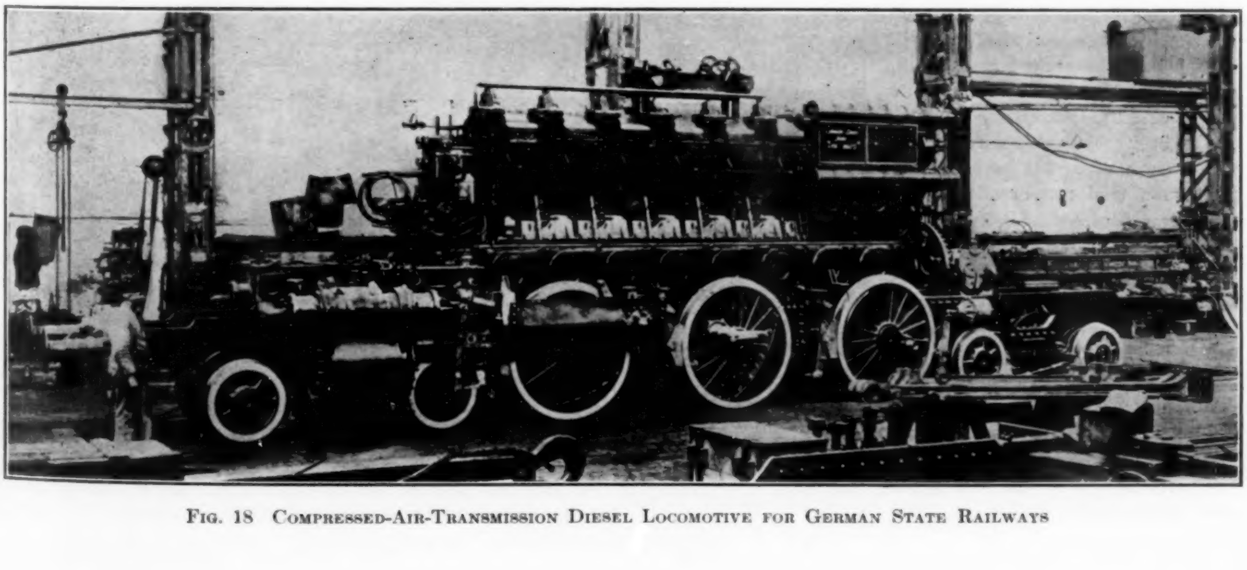


Fig. 18 Compressed-Air-Transmission Diesel Locomotive for German State Railways

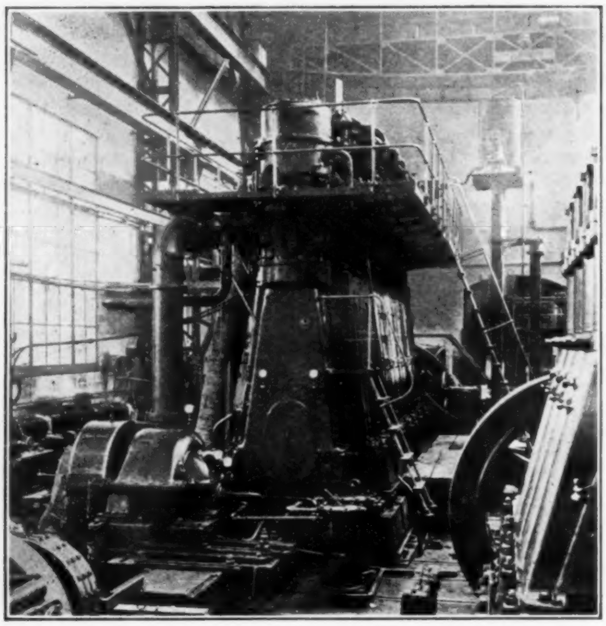


FIG. 19 DIESEL ENGINE WITH BÜCHI SUPERCHARGER DRIVEN BY EXHAUST-GAS TURBINE

motor used in railcars and locomotives with electric drive (except for very small machines).

I have not mentioned aircraft engines, for, while I understand that much research and experimentation is going on both in England and on the Continent, there is no new development about which I am at liberty to make any announcement. Nor have I referred to road transportation except by tractors. Much experimentation is going on with oil engines for trucks of various sizes and types and M.A.N. have supplied over 120 engines of the 4-cylinder type, developing 45 hp. at 1000 r.p.m. for German auto trucks. No doubt the use of heavy oil engines will be extended to road transport but many of our foreign friends, who are best informed regarding such service, especially passenger buses in cities, feel that the cleanliness of gasoline compared with gas oil or other Diesel fuel will keep oil engines out of passenger vehicles for some time to come.

It has been assumed that most readers are familiar with a few large experimental Diesel locomotives which have been built abroad and I will, therefore, only refer to two incidents of that development. Data have recently been released regarding the performance of two Diesel locomotives on a trial run of about 3200 miles from Moscow to Baku and return. Both locomotives were equiped with 6-cylinder oil engines having a maximum rating of 1100 hp. at 400 r.p.m. and a continuous rating of 800 hp. at 300 r.p.m. In one machine the engine was reversible and mechanical drive with a 3-speed gear box and magnetic clutches was employed. The other machine used electric drive. The performances of the two types were substantially the same. The speeds, which averaged about 18 m.p.h., were almost identical. The trailing load did not vary more than 5 per cent. The fuel consumption of the geared locomotive was about 5 per cent less than that of the electric-drive machine on the trip to Baku and about 10 per cent less on the return trip. It varied from about 0.013 lb. to about 0.015 lb. per ton-mile.

The German State Railways are now building a compressed-air-transmission Diesel locomotive at the Esslingen Machine Works. Fig. 18 shows the 1200-b.hp. 6-cylinder, 4-stroke-cycle, 450-r.p.m. M.A.N. engine direct connected to the compressor which furnishes air to the engine cylinders. As the locomotive is not yet completed definite data regarding its performance are not available.

## SUPERCHARGING

Like the evolution from air injection to solid injection, that from inhaling the fresh charge to forcing it in at above atmospheric pressure has resulted from the efforts of many engineers and much research in both Europe and America. As soon as the two-cycle engine with a scavenging pump appeared, and air in excess of the cylinder volume was forced through the cylinder and into the exhaust, the essential features of supercharging were created.

I will not attempt to trace the history of supercharging research and development beyond stating that Dr. Büchi and others have been working at it for about twenty-five years and that it attracted attention in connection with high-altitude flying over ten years ago and began to be generally studied about five years ago. An important European accomplishment is that of Dr. Alfred Büchi, of Winterthur, Switzerland. After several years of research, the Büchi syndicate has been formed and that system is now being used by Deutz in Germany, Werkspoor in Holland, Tosi in Italy, and the Swiss Locomotive & Machine Works in Switzerland, under long-term license agreements and by M.A.N., Harland and Wolff, and others for specific jobs. Up to January 1 of this year 37 engines had been built or were building employing this system. With the exception of five engines ranging from 450 to 750 hp. these are all of from 1200 to 4000 hp. and are for direct-drive ship propulsion and stationary-power-plant service.

Prof. A. Stodola, of the Swiss University of Engineering Science, at Zurich, has recently prepared a report on exhaustive

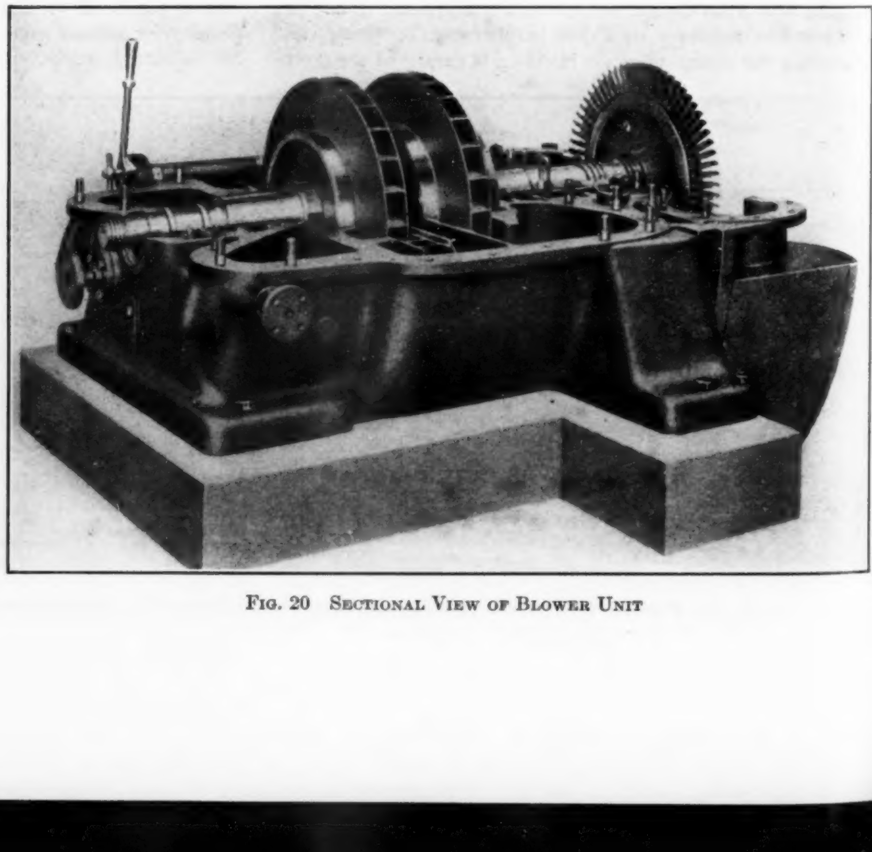


FIG. 20 SECTIONAL VIEW OF BLOWER UNIT

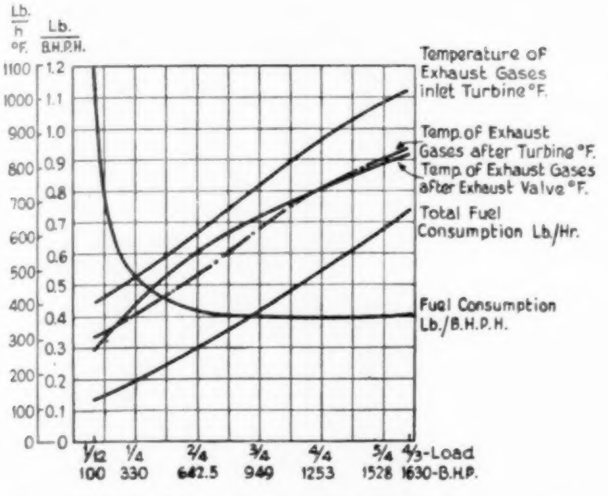



FIG. 21 FUEL CONSUMPTION AND EXHAUST TEMPERATURES, SUPERCHARGED ENGINE

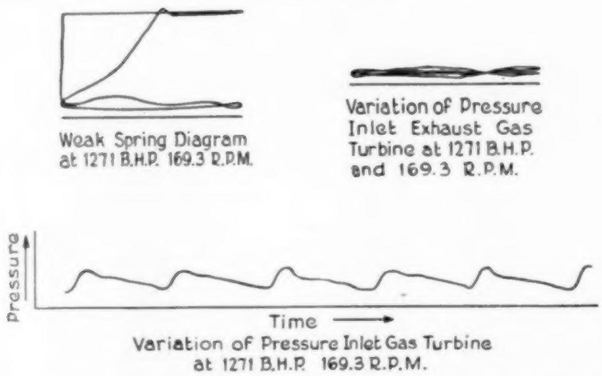



FIG. 22 EXHAUST PRESSURES, SUPERCHARGED ENGINE WITH EXHAUST-GAS TURBINE BLOWER

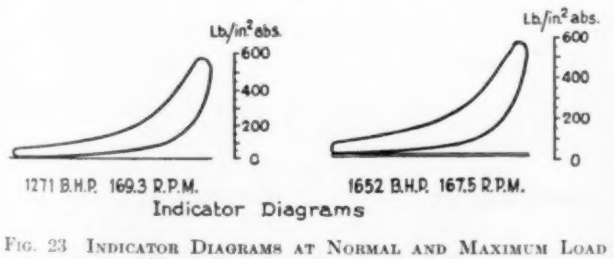



FIG. 23 INDICATOR DIAGRAMS AT NORMAL AND MAXIMUM LOAD WHEN OPERATING SUPERCHARGED

tests of a 6-cylinder, 4-stroke-cycle, 850-b.hp. engine built by the Swiss Locomotive & Machine Works and equipped with an exhaust-gas turbo-blower built by Brown-Boveri & Company of Baden, by means of which the engine has a rating of 1275 b.hp. supercharged and was tested up to 1652-b.hp. maximum load. This report has only very recently reached this country and while it has been translated into English, I will not attempt to give a résumé of it, but will call attention to a few outstanding features of the Büchi supercharging system.

Fig. 19 shows the engine at the Winterthur Works. The exhaust-gas turbo-blower can be seen at the left of the picture by the end of the engine.

Fig. 20 is a sectional view of the blower unit. At the right is the impeller of the turbine and at the left the two blower wheels. The diffusion vanes of the second impeller are adjustable. In order to prevent the exhaust of one cylinder from interfering with the scavenging of another, independent exhaust pipes are provided for this 6-cylinder engine. These lead directly to turbine nozzles so that the exhaust gases mix only after they have passed through the turbine.

Fig. 21 shows the fuel consumption and exhaust temperatures when the engine is operating supercharged. Fig. 22 gives some indication of the exhaust pressures, and Fig. 23 shows indicator diagrams at normal and maximum load when operating supercharged.

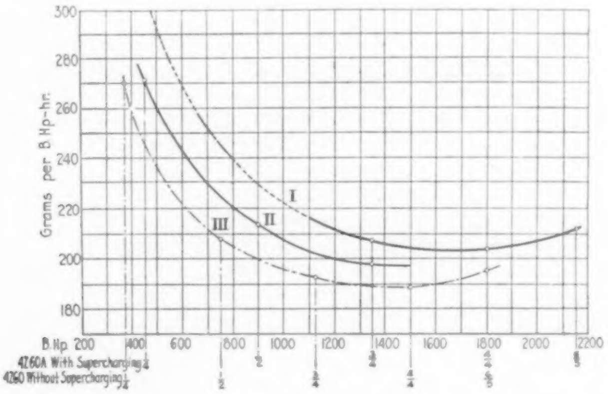



FIG. 24 CURVES OF FUEL CONSUMPTION OF 2-CYCLE DIESEL ENGINES, MODEL 4260A (WITH SUPERCHARGING) AND MODEL 4260 (WITHOUT SUPERCHARGING)

Curve I Engine with supercharging compressor, working with supercharging.
Curve II Engine with supercharging compressor, working without supercharging.
Curve III Engine without supercharging compressor.
(Heating value of fuel, 18,000 B.t.u. per lb.)

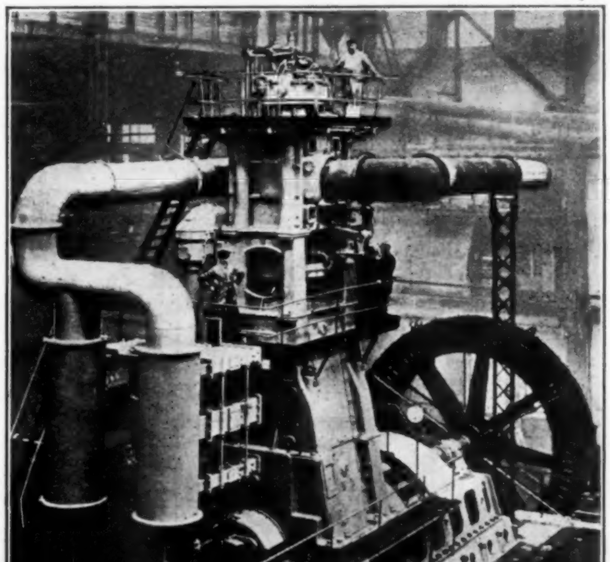


FIG. 25 SINGLE-CYLINDER, DOUBLE-ACTING KRUPP DIESEL ENGINE, 1300 B.HP. AT 84 R.P.M.

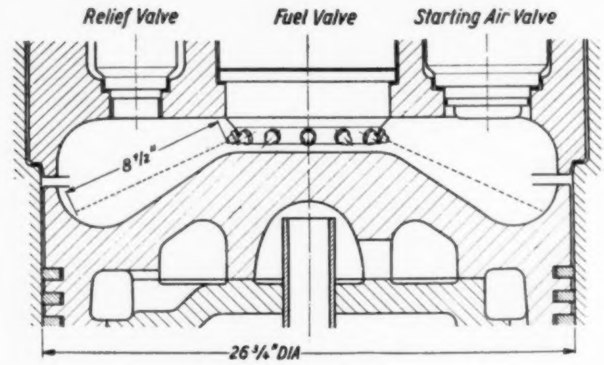



Fig. 26 Top Combustion Chamber, Single-Cylinder, A.E.G.-Hesselman Diesel Engine

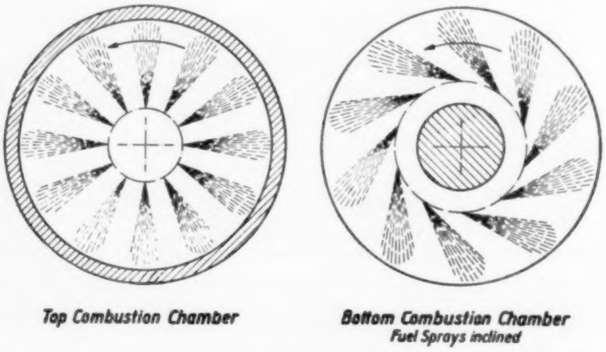



Fig. 27 Arrangement of Fuel Sprays, A.E.G.-Hesselman Diesel Engine

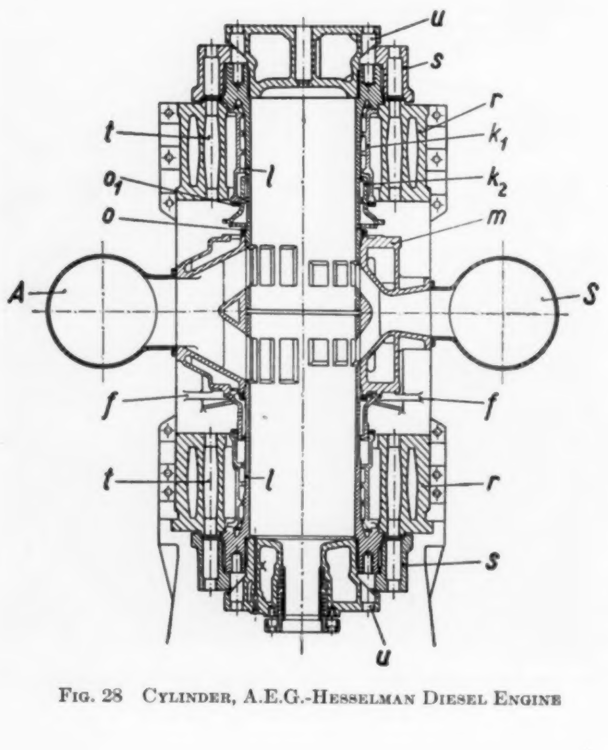



Fig. 28 Cylinder, A.E.G.-Hesselman Diesel Engine

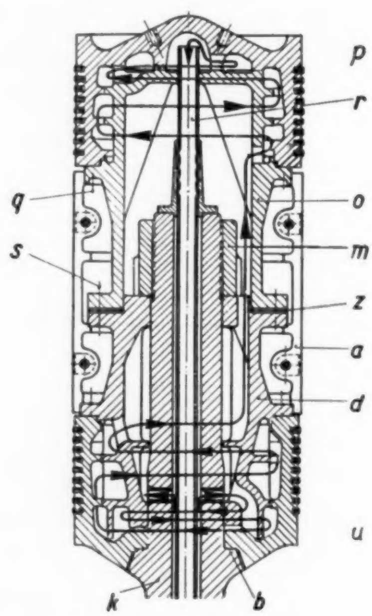



Fig. 29 Piston, A.E.G.-Hesselman Diesel Engine

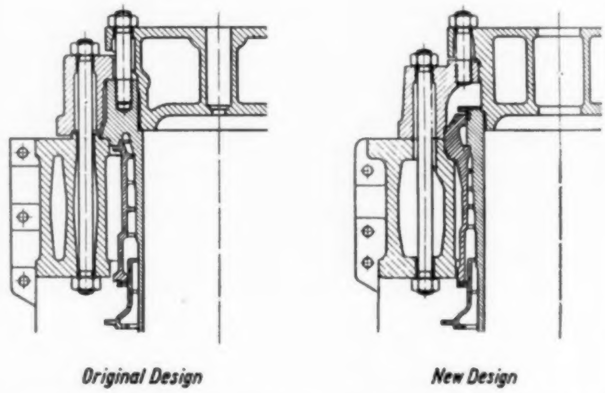



Fig. 30 Cylinder Cover, Liner, and Cooling-Water Jacket, A.E.G.-Hesselman Diesel Engine

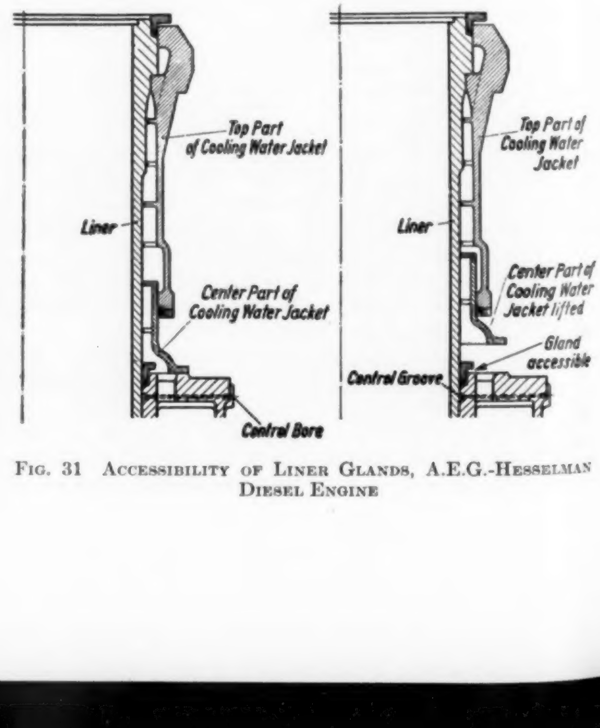



Fig. 31 Accessibility of Liner Glands, A.E.G.-Hesselman Diesel Engine

In summing up the results of his tests, Prof. Stodola said:

1 The Büchi turbo charging system increases the normal output of an ordinary 4-cycle engine by 50 per cent, the maximum output by 100 per cent.

2 The temperatures of the combustion and of the exhaust gases are the same or even lower than with ordinary Diesel engines.

3 The fuel consumption per brake horsepower-hour is lower and less heat is carried away in the cooling water; the absolute amount of the latter is 42,500 B.t.u. per hr. and sq. ft. of the piston areas, a very small amount for this size of engine.

Sulzer Bros. have long employed a system of supercharging their standard 2-cycle engines and, in fact, it was while he was their chief engineer that Dr. Büchi did much of his supercharger experimentation. Sulzer Bros. recommend the use of supercharging only at above three-quarter load.

The curves of Fig. 24 show the performance of an engine rated at 1500 b.hp. without supercharging and 1800 b.hp. with supercharging. According to these data, supercharging increases the continuous full load by about 20 per cent and peak load by another 20 per cent so that the maximum output of the engine supercharged is about 1.44 times the normal continuous load without supercharging.

Supercharging is also being applied by other manufacturers to marine, stationary, and automotive engines.

### Double-Acting Engines

While the opposed-piston type of Diesel, as exploited by Junkers, Doxford, Fullagar, etc.,

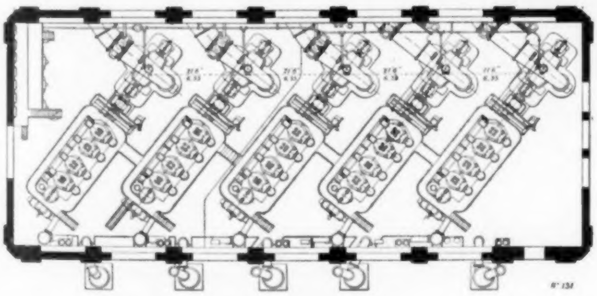


Fig. 32 Arrangement of Five 1000-B.Hp. Carels Engines Direct-Connected to Worthington Pumps at Gladstone Dock, Liverpool

originated about 1900 and was commercial before 1914, I do not know of any double-acting commercial engine until during the last few years. A design involving two pistons and no cylinder covers was easier to accomplish than one piston and two cylinder covers.

One of the first large double-acting engines was the product of the combination of Werskpoor of Holland and the North Eastern Marine Engineering Co., of Wallsend on Tyne. It was a four-stroke-cycle machine, with a single cylinder 800 × 1400 mm. ($31^1/_2$ × 55 in.) and developed 750 hp. at 95 r.p.m. It was tested early in 1924.

Burmeister & Wain are perhaps the outstanding exponents of four-stroke-cycle, double-acting Diesel engines. Their engines of this type are so large, so numerous, and so well known that I will not describe them. Both of these designs are being built by many manufacturers.

The first successful European two-cycle double-acting engine I saw was the single-cylinder M.A.N. machine at Augsburg in November, 1924. As a result of its success, the largest Diesel in the world was built from M.A.N. designs by Blohm & Voss at Hamburg. This engine[3] is in the Electricity Works at Hamburg, and is rated at 15,000 b.hp.

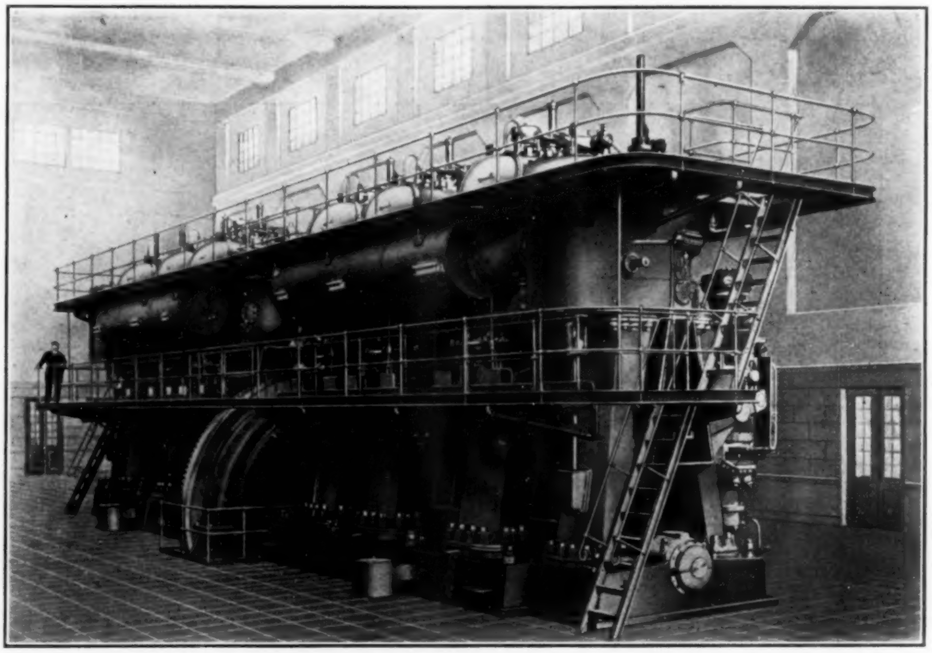


Fig. 33 3000-B.Hp. Carels Engine Now Being Installed at Guayaquil, Ecuador

Dr. Bannwart, director of the Hamburg Electric Power System, recently said of this unit:

Since the set was put in service early in September, 1926, we have not experienced the least trouble, as the motor runs very well and has proved its value as a stand-by in emergencies for a couple of times already. The set is operated for about six to eight hours daily, according to the season. During the months of December and January, the set is operated for two to three hours in the morning and four to six hours in the evening. During these periods the motor carries its full load, i.e., 10,500 kw., and the load is decreased in steps of about 15 min. until the steam plant carries the whole load again and the motor is shut down.

During the normal operating cycle when the engineers are ready for the signal for starting the motor, it takes about four minutes until the generator is connected to the line. The starting of the motor itself takes about three minutes. It has happened a couple of times already that the motor had to be started because of an emergency call from the steam station Tiefstack. Such emergency cases were due to boiler trouble or to sudden fogs which increased the lighting load. In these emergency cases when the engineers are not prepared for the starting, it takes not more than six minutes until the generator is connected to the line.

About three years ago, Krupp built a single-cylinder, double-acting trial engine which developed 1300-b.hp. at 84 r.p.m. It is shown in Fig. 25.

In 1926–27, Sulzer, at Winterthur, built a single-cylinder,

[3] A picture of this engine may be found in the paper by Edward B. Pollister, "The Economic Field for Large Diesel Engines," Fig. 3. See Trans. A.S.M.E., vol. 50, paper No. OGP–50–11.

double-acting experimental engine[4] with a 900-mm. bore and 1400-mm. stroke which developed 2400-b.hp. at 110 r.p.m. Its mechnical efficiency was 70 per cent. This engine has been running over a year most satisfactorily. It has, I believe, the largest capacity per cylinder of any Diesel so far produced. It has a direct-connected two-cylinder scavenging pump and a three-stage injection air compressor.

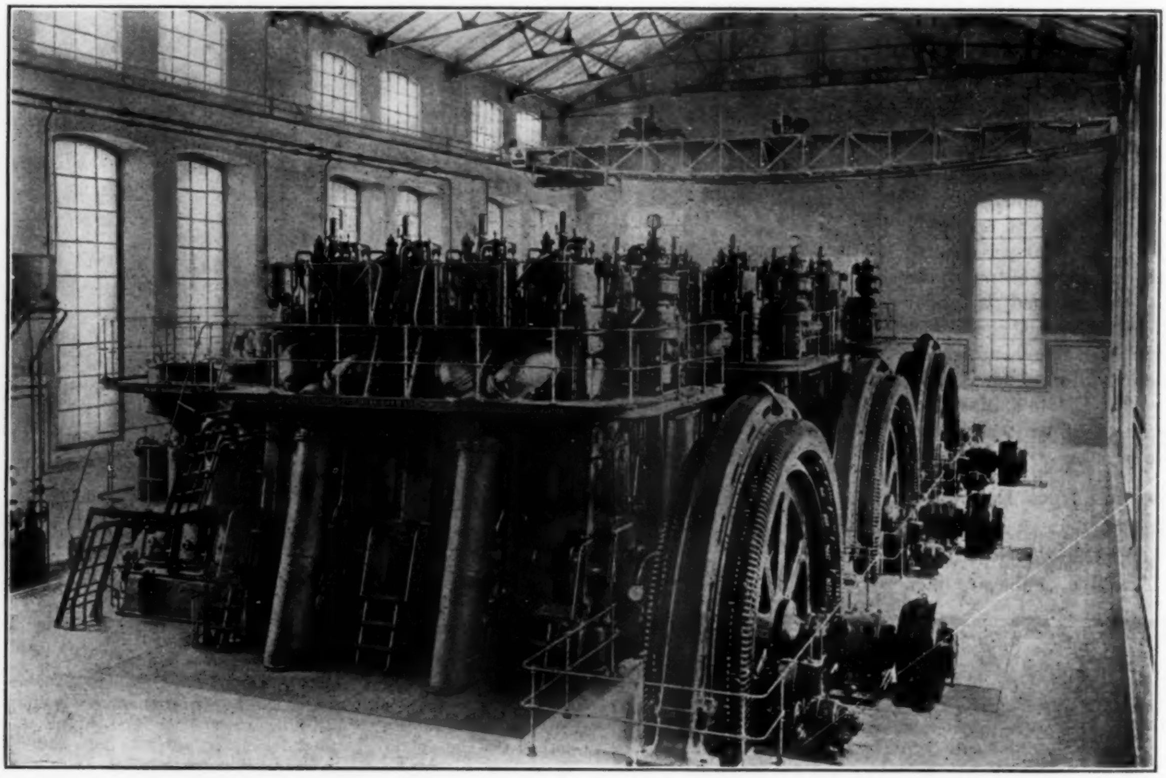
A.E.G. in Berlin were working on this problem at the same time and in 1926 produced a 1000-b.hp. single-cylinder A.E.G.-Hesselman engine. Its dimensions are 680 mm. by 1200 mm. and it runs at 120 r.p.m. In developing this engine, spray penetration and other airless-injection problems were studied, full credit being given to Miller, Beardsley, and others who have been working in this country. As this was the first very large solid-injection engine, a few details will be shown.

and will employ airless injection. At the same time they are building a 7-cylinder engine of the same bore and stroke and 5600 b.hp. at 164 r.p.m. for the Anglo-Chilean Consolidated Nitrate Corp., which will use air injection.

This makes one wonder how long the injection air compressor will survive even on the largest engines.

The large double-acting engines are being built with both direct-connected reciprocating scavenging air pumps and with electric-motor-driven turbo-blowers. It is too early in this development to predict the field in which each type will survive.

It is also too soon to make definite statements regarding the net fuel consumption. Very few data have been released as to the net fuel consumption of these large two-cycle, double-acting engines. That which is available indicates, however, that, after deducting the power required for the scavenging pumps, the fuel consumed at from three-quarter to full load is of the order of 0.39 to 0.4 lb. per b.hp-hr. under the best operating conditions.



[Fig. 34 Diesel-Engine Power Station, Metropolitan Underground Railway, Madrid, Spain

Fig. 26 is a view of the top combustion chamber and the top of the piston, and Fig. 27 the arrangement of the oil spray both top and bottom. Other details are shown in Figs. 28 to 31.

In 1927, Carels in Belgium started to build a 4000-hp. double-acting engine of the type supplied the U. S. Shipping Board by Worthington in this country.

Both Burmeister & Wain and Werkspoor use air injection in their 4-cycle engines. Of the five 2-cycle makes mentioned all but A.E.G. started with air injection. Recently Sulzer have secured favorable results with solid injection in their experimental engine and M.A.N. now have on the test floor at Augsburg two double-acting, 2-cycle engines sold to the Henningsdorf electric power plant, Berlin. Each of these develops 11,700 b.hp. in 10 cylinders, 600 mm. by 900 mm., at 215 r.p.m.

### Power Stations

Diesel engines have been used in power stations since the start of the industry and they have been direct connected to generators for about a quarter of a century. Generally speaking, up to 1918 Diesel engines were not used in power plants requiring maximum reliability and were generally not recognized as equal to steam engines for service where continuity of operation was an important factor. One exception to this was the installation at the Gladstone Dock, at Liverpool, where five Carels 1000-b.hp., 4-cylinder, 2-cycle, single-acting engines direct connected to Worthington pumps were installed in 1913. This is believed to have been the largest Diesel plant in England at that time. Fig. 32 shows the arrangement of the station.

These engines have been in continuous service and were not

[4] A picture of this engine may be found in Fig. 4 of the paper by Edward B. Pollister on "The Economic Field for Large Diesel Engines." See Trans. A.S.M.E., vol. 50, paper No. OGP-50-11.

re-conditioned until last year when an addition was made to the Dock. They are now available for another fifteen years' duty.

Another outstanding installation of long service is the Shanghai, China, power station, which, I believe, is the largest Diesel stationary power plant in existence. This has five engines totaling 20,000 b.hp. built by Sulzer Bros. of Winterthur, which at their guaranteed 20 per cent overload represent 24,000 b.hp. output.

A 5250-b.hp. Sulzer, 2-cycle, single-acting engine has been dispatched as an additional unit in the Shanghai plant.[5] The larger engines in this plant, including the new one, are of the 2-cycle type especially arranged for burning heavy fuel at all loads and this engine showed during the trials the full-load fuel consumption of 0.414 lb. per b.hp-hr. with 18,000-B.t.u. oil. Reference has already been made to the large power plant at Hamburg and Berlin.

Another important installation is that of three M.A.N. 4-cylinder, double-acting two-cycle engines developing 2250 b.hp. at 150 r.p.m. for the Metallurgical Works, Roter Oktober, at Stalingrad, Russia.

Fig. 33 shows one of a pair of 3000-b.hp., 6-cylinder, 2-cycle single-acting Carels engines now being installed in a central station at Guayaquil, Ecuador.

The first direct-connected generating units like the Liége machine had separate flywheel and generator which is the design that has been generally followed in the United States and England. The Continental development, however, has been in the direction of combining the generator rotor and the flywheel to save space and weight. The station of the Metropolitan Underground, at Madrid, with three 1500/1800-b.hp. Sulzer engines in it, illustrates the flywheel type. See Fig. 34.

The generator of the 15,000-hp. engine at Hamburg is of the normal type because of the uniform torque effort of nine double-acting, 2-cycle cylinders, and there is a strong feeling that as the number of cylinders and rotating speed increase, as typified by the two 11,700-hp. Henningsdorf engines of 10 cylinders, 215 r.p.m., the flywheel problem will become as simple as it was with high-speed reciprocating steam engines.

The power plants of the character which I am describing have represented a quality of installation equal to that of the very finest steam and hydraulic plants and the quality of the

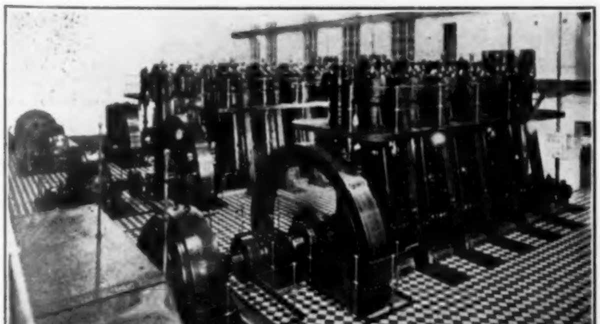


Fig. 35 Concordia Power Plant, Engine Room From Switch-Board Gallery. Three 780-Hp. Carels-G.E. Sets

Continental engines combined with this high-grade station design and intelligent supervision have combined to produce power plants which are fully equal to any other type as to reliability and continuity of service.

Fig. 35 is a view from the switchboard gallery of the concordia power plant, Argentina, and shows three 780-b.hp. 4-

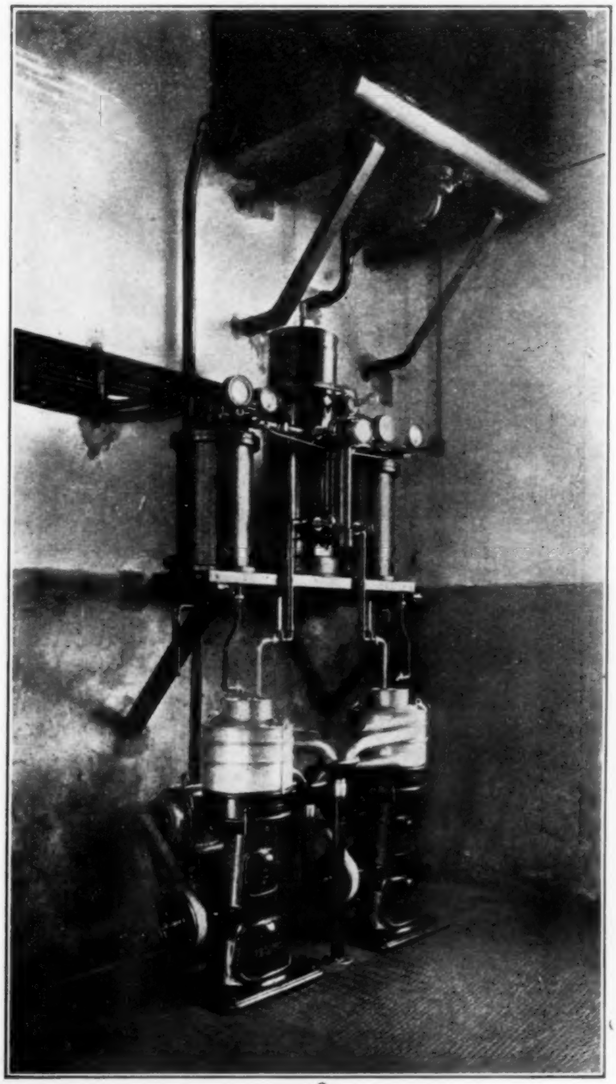


Fig. 36 Centrifugal Pumpers for Fuel Oil, Concordia Power Plant
(Note two electrical and one water heater.)

cycle Carels engines. The arrangement of the oil centrifuges is shown in Fig. 36.

### Marine Engines

The first direct reversing marine Diesel engines were, I believe, of the 2-stroke-cycle, single-acting type and were first built about 1907 by two or more manufacturers. At that early date marine engines of 1000 hp. were manufactured. In the intervening ten years, the marine Diesel has taken the leading position in ship propulsion indicated above, and according to Lloyds, Register of July 5, 1927, there were over 500 full-powered Diesel-motor steel ships of over 2000 gross tons in actual service. These include ocean-going liners as large as any except a few of the great trans-Atlantic high-speed passenger ships.

Both the 4-stroke-cycle and 2-stroke-cycle types have been developed up to the largest sizes in several countries and airless injection is now being applied by at least two Continental manufacturers and one in England to very large marine engines.

Reference has been made to the Kitson-Still locomotive engine. The original Still idea of combining an oil engine and steam engine

[5] A picture of this unit may be found in Fig. 10 of the paper by Edward B. Pollister, Trans. A.S.M.E., vol. 50, paper No. OGP-50-11.

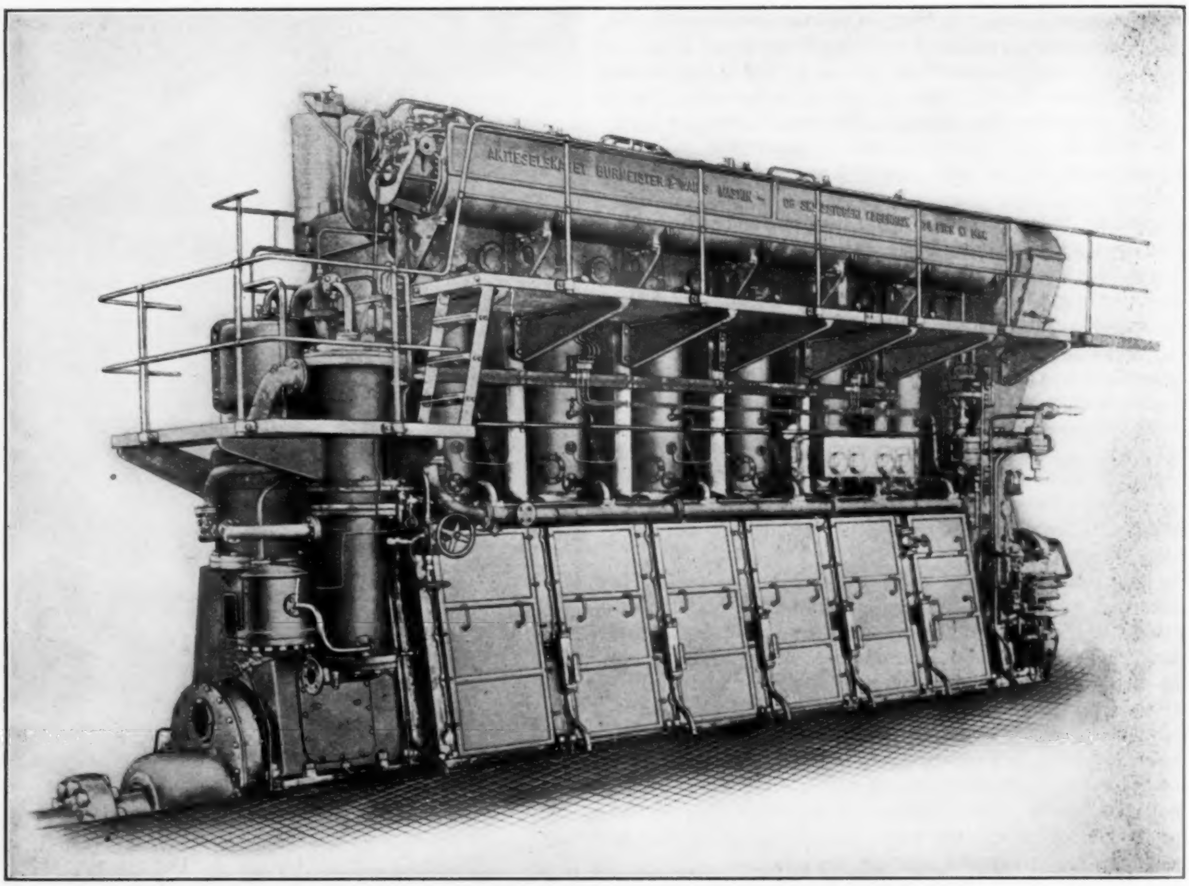


FIG. 37 ONE OF THE MAIN DIESEL ENGINES INSTALLED IN *MS. Britta*

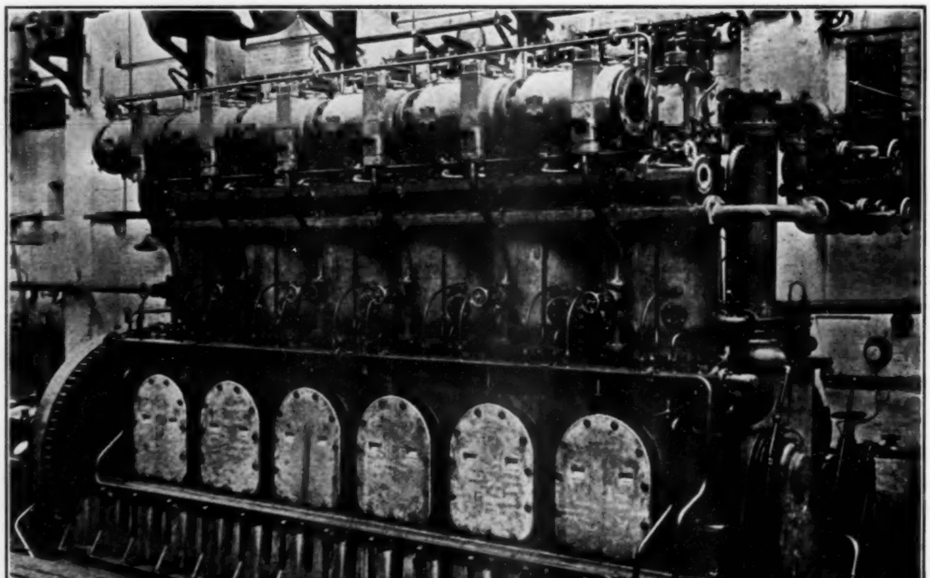


FIG. 38 DIESEL ENGINE FOR *MS. Brunswick*

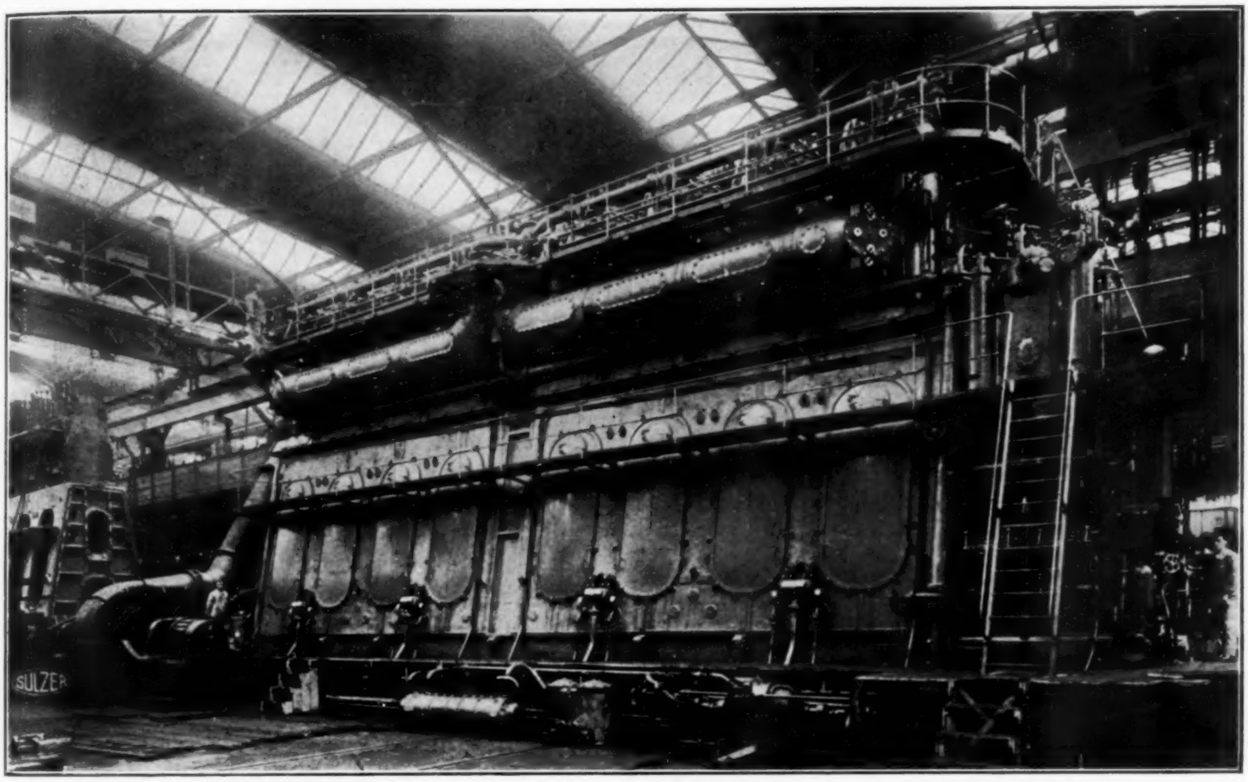



Fig. 39 8-Cylinder Sulzer Marine Engine

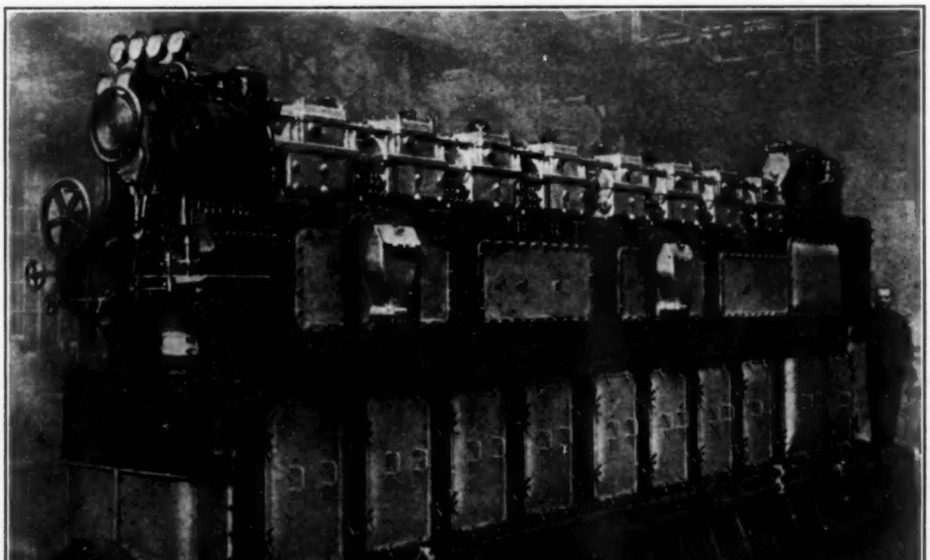


Fig. 40 Fiat Marine Diesel Engine for Submarines

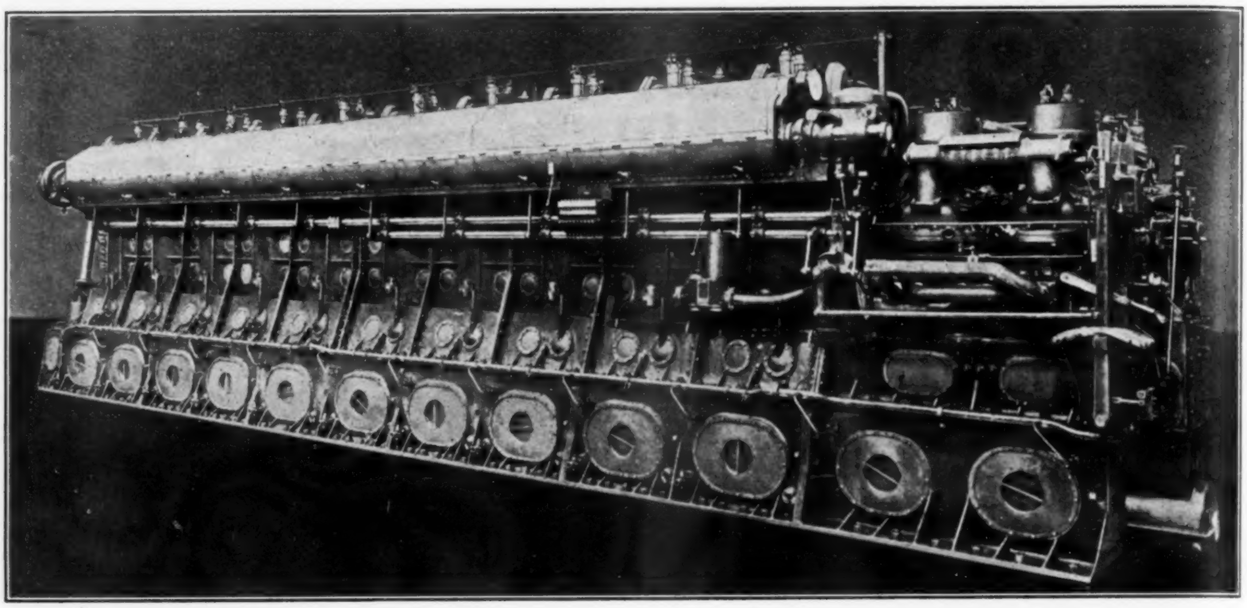


FIG. 41 M.A.N. MARINE DIESEL ENGINE FOR SUBMARINE

in the same cylinder with a single piston has been adhered to in the locomotive. It is interesting to note that in building two 2500-s.hp. Scott-Still engines for the motor vessel *Eurybates*, the Scott Shipbuilding & Engineering Co., Ltd., of Greenock, while retaining the solid-injection fuel system have separated the oil and steam cylinders. A diagram appearing in the *Engineer* of London, of March 30, 1928, shows these new engines. The oil-engine cylinders are of the normal 2-cycle, single-acting type with a few of the special Still features and a scavenging air chamber below the piston which takes the air from the turbo-blower before it enters the cylinder. The steam-engine part of the unit is designed according to standard marine steam practice.

This shows reversion to a simpler type on the part of the Still people in England and points in the same direction as the abandonment of the injection compressor for large marine engines by the A.E.G. and others, and is an added indication of development in the direction of simplification and reduction in weight which should still further enlarge the field of Diesel application.

The installation of beautiful, big Diesel engines in ships is going on so fast that it would be easy to show hitherto unpublished illustrations of the boats, the engines, and their auxiliaries, but only one or two more indications of present-day tendencies will be cited.

Fig. 37 shows Burmeister & Wain's 6-cylinder, 4-cycle, single-acting, trunk-piston Diesel engine developing 3000 i.hp. at 145 r.p.m., of which two have recently been installed in the twin-screw motor tanker *Britta* built at Helsingfors and may be taken as typical of direct-drive motor-tanker engines.

The United States has taken the lead in the introduction of electric drive for ship propulsion. With Diesel engines this has been applied to tug boats, ferry boats, yachts, and tankers, but has not been introduced in Europe as extensively as here.

Another instance of the effect of American developments on European practice is the equipment of the motor tanker *Brunswick* being built by Scotts for the Atlantic Refining Company. The propelling machinery which is now being installed will consist of four six-cylinder, 750-b.hp. Carels-Ingersoll-Rand engines as shown on test in Fig. 38, each direct connected to a continuous-current generator. The vessel will have a single-screw, electric-motor driven. This is the largest Diesel-electric equipment so far produced abroad and is also another example of international cooperation, as the hull is built in Scotland, the electrical machinery by the British Thomson-Houston Company, affiliated with the General Electric Company of the United States, and the oil engines by the Carels Works in Belgium from designs supplied by the Ingersoll-Rand Company.

Fig. 39 shows a Sulzer 8-cylinder, 820 × 1440 mm., 2-cycle, single-acting engine developing 7000/8000, b.hp. at 100 r.p.m. with separate motor-driven scavenging blower illustrative of

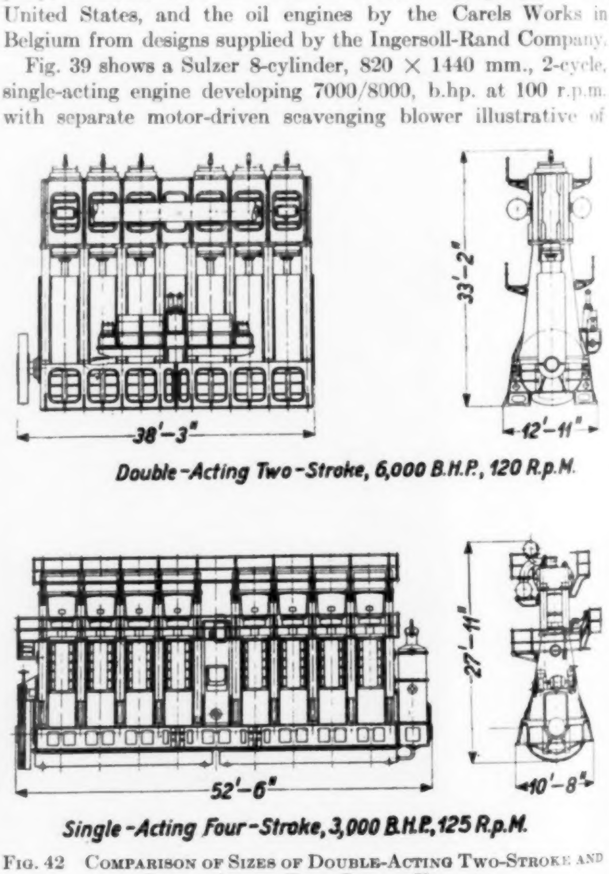



FIG. 42 COMPARISON OF SIZES OF DOUBLE-ACTING TWO-STROKE AND SINGLE-ACTING FOUR-STROKE ENGINES

the largest 2-cycle air-injection marine engines now being built.

The development of the Diesel submarine type of engine is still going on in Europe. Fig. 40 shows a 2200-b.hp., 380-r.p.m. Fiat engine and Fig. 41 a 3000-b.hp., 390 r.p.m. M.A.N. engine.

I have referred to the importance of reduction in weight in reference to automotive engines. Incidental to reduction in weight, there is a reduction in space. This reduction in dimensions is essential for the increase in capacity of automotive engines because of the limitations of clearance diagrams. In the case of stationary engines, reduction in weight and size means a saving in transport and power-house structure costs. When we come to marine engines, in addition to the first cost of the space in the hull taken by the propelling machinery, there is the question of the earning capacity of space saved when propelling machinery of smaller dimensions can be used. For some classes of vessels this is a very important factor, and the introduction of the double-acting engine has had a marked effect on this.

Fig. 42 shows the comparative space occupied by one 6000-b.hp. double-acting, 2-stroke-cycle engine as compared with one single-acting, four-stroke engine of half the output.

Very little reference has been made to fuel economy, chiefly because the improvements in fuel consumption are not of great magnitude and are of minor importance compared with the design problems, the solution of which produces Diesel engines giving reliability and continuity of service equal to the best steam and hydraulic plants and those which will effect reductions in weight and increases in rotative speed essential to the expansion of all kinds of applications and especially those concerned with transportation. One example of what a motorship is doing will be given.

No doubt there are many other equally good examples, but I have selected this one because Mr. James Smith, superintending engineer of the Union Steamship Co., of New Zealand, when passing through this country on his way to England a few weeks ago allowed me to copy some data from his personal log book and has authorized me to publish them. This is, therefore, first-hand, accurate information secured from the owners. These data refer to the *Aorangi* which was built by Fairfield in Glasgow. It has four two-cycle, six-cylinder, 3000/3600-b.hp. Sulzer Bros. engines. The *Aorangi* has made over 300,000 miles in the Pacific Service. Up to the end of 1927, when the engines were first overhauled, its performance had been as follows (figures refer to English long tons and imperial gallons):

Total distance, voyages, 201,043 nautical miles
Average speed, 16.44 knots
Total fuel, propelling, 23,359 tons
Fuel for other purposes, 4891 tons
Fuel in port, 2605 tons
Engine hours, 12,224
Average i.hp. propelling, 14,710
Average fuel per day propelling, 45.8 tons
Average fuel per day for other purposes, 9 tons
Average fuel per i.hp., 0.29 lb.
Total lubricating and cylinder oil, first year, 41,749 gal.
Total lubricating and cylinder oil, second year, 28,542 gal.
Lubricating and cylinder oil used in port, first year, 2652 gal.
Lubricating and cylinder oil used in port, second year, 1550 gal.
Lubricating and cylinder oil used per day, first voyage, 294 gal.
Lubricating and cylinder oil used, average last four voyages, 110 gal.
Average speed three best voyages, 17.1 knots
16.96 knots
16.88 knots
Highest daily speed, 18.1 knots

Now after going about 300,000 miles, the fuel per indicated horsepower on the voyage of December, 1927, was 0.311 lb. and for January, 1928, 0.315 lb.

Mr. Smith showed me the log of fuel consumption for a large number of voyages and it is amazing how little variation there is in the amount of fuel per voyage. The systematic and regular way in which this ship behaves in the matter of reliability, low maintenance, and uniform economy of fuel and lubricating oil is certainly a strong argument in favor of Diesel propulsion.

# Cooperative Diesel-Engine Research

By HARTE COOKE,[1] AUBURN, N. Y.

In order to get the best idea of the problems requiring cooperative research on the Diesel engine today, a sketch of the origin, uses, and past research on this subject should be given. The type of internal-combustion engine which operates on what is called the "Diesel cycle" was originated by Dr. Diesel in his efforts to improve the efficiency of the ordinary gas engine, his idea being to see if lower power costs could be obtained for operating refrigerating machines. His investigation showed him that an increase in the efficiency of the gas engine could be obtained by an increase in the compression ratio of the engine, this in the ordinary gas engine being limited to the compression at which fuel would ignite. He concluded that if he could compress the air only, and put the fuel in when the compression had been accomplished, he could get the compression ratio which would give the highest efficiency without limitations of preignition present in the ordinary gas engine.

His theoretical investigation of this cycle of operation was complete, and he wrote and published a book on this before any actual engine had been built, and the writer believes this is the first time anything of this kind was done. The usual process is to develop a machine, later on investigate its various principles and limitations, and then papers and books are usually written after the thing has been accomplished.

As this investigation showed promise of lower power costs, commercial firms in Europe were finally induced to develop the actual engine, and it is interesting to note that the original development of the Diesel engine was a cooperative process. A number of industrial firms in Europe joined to develop an engine with this cycle of operation suitable for commercial service.

The original idea was to use powdered coal as fuel, but on account of the complications and difficulties in accomplishing the desired results along these lines in connection with the high pressures and high temperatures which were much beyond the temperatures and pressures at which much experience had been obtained up to that time, the simpler and more satisfactory method of using hydrocarbon oil as fuel was adopted, the oil being atomized and introduced into the cylinder at high pressure by compressed air at a sufficiently higher pressure than the compression, not only to put the oil in the cylinder but also to atomize it, so that it would burn quickly and completely. With the initial problem solved by cooperative effort, the various firms that had joined in this work started the production of Diesel engines commercially.

The original idea was an engine which would reduce the fuel cost, as the cost of fuel in Europe at that time was a very large factor in the cost of power, and the very high efficiency of the Diesel cycle of operation would make a material reduction in the fuel costs for producing power. When these engines were put to work in actual service, it was found that there were other savings in the cost of operation, such as the lower labor cost per unit of output and lower maintenance than with a steam station, also that it had other advantages such as complete absence of standby losses while the engine was shut down, and the ability of the engine to take full load at short notice.

### First Diesels Were Single-Acting

The original engine was developed as a four-cycle engine with air injection, and in order to reduce the first cost a start was made to develop the Diesel engine working on the two-cycle principle so as to get more output from a given engine. These early engines were all single-acting.

These engines gradually came into service, first for central stations for driving generators and in industrial power plants, both as belted units and as engines coupled to a generator so that power could be transmitted through the works to various electric motors. On account of the low operating cos's, these engines began to be used for driving pumps, because in a pumping plant the load factor is usually very high, and the lower operating costs would justify the high first cost of the engines at that time. On account of the absence of standby losses and the ability to take on a load at short notice, these engines came into use as auxiliaries in water-power plants.

It was early seen that this type of engine had a great many advantages for marine use, and installations were made on various vessels, some of the first being with Diesel electric drive, the idea being to use moderate-sized engines at fairly high speed and a slow-turning motor on the propeller. However, owing to the lack of development of marine electrical equipment at this time more or less trouble was had, so that the direct drive which had been tried out in several cases proved to be more satisfactory, and the engines were made in larger and larger sizes for direct drive for various vessels.

These marine engines for direct drive had to be made reversible, which proved to be a problem easily solved, and a great many of the early vessels were made with the twin-screw arrangement, for the reason that the engines available were only of moderate power and to get the amount of power required for a given vessel the twin-screw arrangement seemed to be the best way.

Among the problems of the Diesel-engine builders as this development went on were first the limitations as to what output could be secured from a given engine; and the reliable Diesel-engine ratings today are based on actual experience with the operation of Diesel engines at certain ratings rather than on any theoretical determination or test demonstration of what the maximum possible output might be. There were also problems of materials, as in the early development of this industry materials were not available that are available today, neither was the information on the characteristics of the different materials as complete as it now is.

They also had problems in regard to fuels, as then they did not understand the effect of the different fuel characteristics nor were the quantities and qualities of fuel available that are available now. There were also problems of lubrication, as it was not understood at first just how the cylinder lubrication could be taken care of under the conditions of the extreme pressures and temperatures which this cycle of working developed.

In regard to the research which was conducted during this period, a good deal of research was conducted by the individual manufacturers to perfect the various arrangements for the preparation of fuel for combustion in the cylinder and the shape and arrangement of the combustion space. In regard to research on the output limitations, this was regulated more by actual experience and practice than by any special research that could be carried out. Oil engines could develop considerable power under test conditions, but it was found in actual practice that it was advisable to carry a lower load than test results showed it was possible for the engine to develop.

When the metallurgists found what characteristics in a ma-

[1] Engineer, McIntosh & Seymour Corp. Mem. A.S.M.E.

Presented at the First National Meeting of the A.S.M.E. Oil and Gas Power Division, the Pennsylvania State College cooperating, State College, Pa., June 14 to 16, 1928.

terial were desired, the metallurgical research developed materials that were more advantageous for the various uses than had been previously available. In regard to fuels, as time went on experience developed difficulties with certain fuels, and the use of these fuels in actual service usually developed the cause of the difficulty, so that the remedy could be applied and the particular fuel in question made usable.

In regard to troubles with lubrication, as experience developed with these engines it was found that some of the early fears in regard to lubrication problems were groundless, and the oil men when they found just what characteristics were desirable for use in a Diesel engine were able to produce oils which would render the satisfactory service desired.

### Larger Fuel Supply Made Available

During this development, the period of the war came on, and the necessities of war caused a very rapid development of the types of Diesel marine engines which had proved so suitable for use on submarines and developed materials and processes which eventually proved to be of advantage to the Diesel-engine manufacturer; but another change, which was the rapid introduction and use of the automobile, gave a very rapid development by the metallurgists of materials and also information on the use of heat treatment of materials which was a great help to the Diesel-engine industry. Also with the tremendous increase in the use of the automobile, petroleum supplies were developed to a tremendous extent, and the great demand for gasoline improved processes of refining crude petroleum, so as to give enormous supplies of suitable fuels for Diesel engines, and also the experience gained with the lubrication of engines for automobiles proved to be of great benefit to the lubricating engineer in taking care of the lubricating problems on the Diesel engine.

Now that the Diesel-engine industry has the tremendous benefit of development in other lines, all these things have facilitated the commercial development of the Diesel engine itself. At the present time the use of the Diesel engine is more diversified than ever before. Stationary engines are used in a great many central stations, and when we hear of central stations we always think of magazine descriptions of plants with a capacity in the hundreds of thousands of kilowatts, but as a matter of fact, the size of station that is usually installed is the one that can best serve the particular neighborhood where it is used, so that in general the average Diesel engine used today is somewhere between 300 and 800 hp.

Such engines are in use in central stations, cement plants, oil pipe-line pumping stations, flourmills, and various industrial plants, brick-making plants, plaster mills, city waterworks, for irrigation, for drainage pumps, for marine service, and they are coming into use as the main drive on the very largest and fastest ships and are now built in sizes so that they can be used for single-screw vessels up to the largest tonnage that is desirable for the usual freight service.

This development has been along not only the four- and two-cycle air-injection line, but also mechanical injection has been developed for both four and two cycle. In addition to this, the largest sizes, both four- and two-cycle, have been built double-acting, which gives a reduction in the weight and a reduction in the first cost. This type of engine has also proved to be very desirable for auxiliary service on shipboard, and all modern motorships have Diesel electric units to furnish electric power for auxiliary service.

The Diesel engine has also proved very advantageous for use on dredges, and is used for direct drive on main dredging pumps, also for driving the auxiliary equipment by means of shafting and clutches and by having an engine connected to a generator so that the various auxiliary equipment can be driven by motors. Some of the larger dredges have Diesel engines coupled to generators, and all of the auxiliaries including the main dredging pump driven by electric motors. This arrangement allows full power to be applied to the dredging pump at low heads, which is very advantageous.

The Diesel engine has now invaded the railroad field and has been used in Europe on smaller locomotives and railcars for about a dozen years. The use for railcars has just started in this country, and a number of Diesel engines have been built for use on switching locomotives. Practically all of these have been electric drive; that is, the Diesel engine is coupled to a generator, and regular electric motors are used on the driving axles.

While the peculiar tractive-effort characteristics of the Diesel locomotive make it especially desirable in switching, and where the freedom from smoke and noise is also of advantage in populous districts, it has been found that the operating costs are very low, which makes the use of the Diesel engine for main-line locomotives very desirable, and it is actually coming into use for this particular service.

### Diesels Desirable in Aeronautic Field

In addition to this, there are special cases where use of the Diesel engine seems very desirable, such as for aeronautics. While at present the weight of the Diesel engine is a drawback for use in this service, the fact that it can use a very safe fuel is a very desirable feature for aeronautic use.

In general, the Diesel engine as it stands today has reached practically the same state of development as other power equipment such as the steam engine and the turbine. The main problems have all been solved, and efficient, reliable service has been demonstrated in a great many lines of use.

While, as mentioned, the main problems have all been solved, an advance could be made if more complete information could be obtained in regard to some of the fundamental things connected with the operation of a Diesel engine, such as more complete knowledge of the nature of the combustion; the characteristics of the products of combustion at the high temperatures and pressures obtaining in a Diesel engine; the characteristics and nature of the ignition of fuel at these high temperatures and pressures; more complete information in regard to the transfer of heat from this mixture to the walls; a coordination of the information now existing in regard to the transfer of heat through the walls to the water jackets; a more complete knowledge of the desirable characteristics of the walls and other parts that are exposed to the high temperatures so as to resist not only the temperatures but also the natural wear.

These problems of the Diesel engine are along much the same lines as has been the case from the first, the most important one being the combustion characteristics of the engine, which with the design of the engine, especially the parts in connection with the combustion space, and also the materials used for this part of the engine, have an important bearing on the size and output limitations.

Those three things also have a bearing on the maintenance of a Diesel engine, and the maintenance further depends on the lubrication, and the cooling, and the nature of the cooling water used. For special cases such as for railway work, the output limitations will require special investigation, and also the question of weight will have to be carefully gone into.

In regard to the special uses for aeronautics, the weight of the Diesel engine is a vital factor in this case, and the output limitations will have to be especially investigated to secure the light weight desired and as high speeds will have to be used, special investigation will have to be made of the characteristics of the

fuel consumption at these high speeds. In regard to the solution of these problems, research in various degrees is now being carried out by industrial concerns and government departments.

For instance, in regard to the aeronautical use of the Diesel engine, the National Advisory Committee for Aeronautics has conducted very interesting and complete tests on the output limitations, fuel consumption, and weights of the Diesel engines for this use.

Now in the building of a modern Diesel engine, the manufacturers avail themselves of the special knowledge of the metallurgists and of the steel works for the furnishing of the crankshaft for the Diesel engines. Standard parts, such as standard studs and nuts, are bought of concerns who specialize in these particular things. Gages, thermometers, lubricators, piping, and the valves and fittings for this piping are all bought from specialists; also the seamless tube for high-pressure piping, seamless air receivers, and riveted air receivers are the product of specialists.

It is when Diesel engines are in actual service and being operated by the user that the problems which have to be solved are developed. In England there was an association of users of steam equipment, known as the Manchester Steam Users Association, which made periodic inspections of the steam plants of all the members and made a paintaking investigation or research in connection with every failure of a boiler or engine part, and the effect of this cooperative research was very beneficial to the users of the boilers and steam machinery and had a profound influence on the design ot this equipment. The Diesel engine users in England have had for years an association where they could compare notes and look into the problems of the individual members and by this cooperative effort improve the operating results.

### Research Interests Many Lines

In view of all this, such problems as come up regarding improvements of the Diesel engine are of interest not only to the Diesel engine builders but also to these other industries, such as the petroleum industry which furnishes the fuels and lubrication for these engines, and to the many lines of industry which are users of this equipment.

In addition to this, the solution of some of these problems would be of benefit to still other industries; for instance, the transfer of heat from gaseous mixtures to the walls of the Diesel engine involves a careful investigation of the problem of heat transfer, which would be of advantage not only to Diesel-engine builders but to builders of steam locomotives, boilers, radiators that are used in the heating of buildings, and to the builders of radiators for cooling automobiles.

In view of the cooperation of a number of industries in supplying materials which go to make up a modern Diesel engine, it would be desirable for these industries to cooperate, and also for the Diesel-engine builders themselves to cooperate, and also the various other industries that would be benefited by special research on problems specifically brought up by the manufacturer of Diesel engines in the solution of such problems as may appear.

Just how this research should be conducted or supported is a question that should be taken up and settled to insure the quickest and best development of the Diesel engine. Cooperative effort along various lines is now seen commercially among manufacturers who are cooperating to educate the public in regard to the use of cement. This is also true of the hardwood lumber merchants, brick manufacturers, and a number of others.

In England the Government authorities have seen the desirability of assisting and advising in the research necessary to industrial life, and as far as this has gone it has proved very beneficial.

In this country we have the Bureau of Standards, which has done a great deal to assist our industries in solving some of their problems and improving their processes. Various government bureaus have departments of research. The Bureau of Aeronautics of the government has a wonderful research department which has accomplished a great deal, and both the army and the navy have conducted considerable research into their various problems.

Some of the larger industries in this country maintain extensive research departments, such as the General Electric Company, Westinghouse, the Western Electric, American Telephone and Telegraph, American Radiator Company, and General Motors Corporation.

A good example today of cooperative research is the Nela Park Laboratories of the General Electric and Westinghouse companies, which devotes its entire attention to the improvement of the electric incandescent lamp and the methods of its manufacture. The modern incandescent lamp illuminates this research problem, and its cheapness and efficiency today show how desirable the activities of such a cooperative research can be.

However, it is only the largest concerns that can afford to carry on such research as is now desired, and in this country government agencies cannot be expected to solve all the problems of industry, nor would this be entirely desirable. Also, a great many industrial concerns do not have the resources to do this as thoroughly, completely, and quickly as is desired, nor can the existing facilities for research and apparatus and personnel which are available at the various colleges be called upon or expected to do this work unaided.

A good example of this cooperative research has already been set by the petroleum industries, which have already inaugurated a very extensive program of research, coordinated by the American Petroleum Institute, which has arranged to coordinate a great part of the technical activities of the oil industry.

It would seem from all of this that the best solution of this problem of Diesel-engine research would be for industry as a whole to cooperate in supporting such research as was desired, and in the author's opinion this research could best be conducted and directed by such a disinterested body as The American Society of Mechanical Engineers.

## Discussion

R. J. S. Pigott.[2] After an association of some 14 or 15 years with the Research Committee, the first thing that occurs to me when it is mentioned is, "Where is the money?" Perhaps you may not realize it, but over two-hundred million dollars a year is expended in the Government and private laboratories. There are some large units, such as the General Electric Co., which alone spends between seven and eight millions a year; the American Telephone & Telegraph Co., which spends a little more than that; Western Electric, with probably two or three millions; Westinghouse, with two or three millions; Aluminum Company of America, two or two and one-quarter millions. And then there is an enormous total amount of money spent by the smaller groups, eighty or ninety millions of dollars a year for research work.

In addition to that there are various trade associations spending a great deal of money on research work, this money coming from their own membership. There are a number of very large research endowments, none of which, however, is directed toward industrial research; for instance, the Rockefeller Foundation, 165 million, which is used exclusively for research in the medical profession; Mellon Institute, which is devoted to chemistry; and also the Carnegie Institute, which covers pure science which

[2] Consulting Engineer, Public Service Production Co., Newark, N. J.; Chairman, A.S.M.E. Standing Committee on Research.

none of the other groups has attempted. They have a twenty-two million dollar endowment.

The smallest of all is the Engineering Foundation, which has about six-hundred thousand dollars, and that amount is insignificant compared to the problems coming before it.

So far as the Society is concerned, we have no fund from which to draw, except to draw the money from the Engineering Foundation. For that reason we have started a campaign of our own, which I am not at full liberty to mention as yet. Whether that will be successful, I do not know. If we are successful in getting such an endowment, this question of research for industrial purposes will be solved. Until that time we must pursue our labors by the same method that we have during the past 15 years. We need funds and we need the cooperation of those interested in the furtherance of this work.

In our experience with several different groups, I might exemplify it by mentioning the Fluid Meters Committee. This committee was made up first of a small group of users, and later it was found that the information could be obtained only through the manufacturers. The textbooks did not have it; the manufacturers themselves had what little information there was that was up-to-date.

We brought into the committee a large number of manufacturers, but toward the end of our work a great many more manufacturers were on the committee than any other class. At first the attitude was somewhat colored by suspicion. Each manufacturer thinks, "Well, am I going to get as much out of this as the others, or can I get a little more than they are getting for the amount I am putting in." If we could get the proper cooperation, then there would not be that suspicion.

However, they found that the things they were doing were not secrets at all in their particular business; they were already known to the others or else they were not worth anything. There are many problems facing you now that could be solved through cooperation and common action. By individual effort you do not get the large spread of specialized skill to bear on the subject, and you do not have funds enough to make it a commercially feasible expenditure.

The characteristics of the problem before you are twofold. Fundamental research covers investigation in the physical properties of materials. As an example, I might refer to the investigations of Professor Schweitzer in relation to the oil-spray atomizers and the action of various oils, etc. That has nothing to do per se with any particular design of engine.

If the work were performed in connection with a particular design, that would be a matter of applied research. As a matter of fact, the kind of research that you in general have to tackle, and that we in the A.S.M.E. can assist in, is applied research, because it shows up so well as bringing back money commercially; if you have to go out and get money from industry, you must show a rather quick commercial return. You will find with rather few exceptions that our work has been largely applied research rather than fundamental research. The exceptions are in the development of standard steam tables and investigations into the physical properties of refrigerants and also some of the work on oil sprays.

It is curious that the steam tables should have brought in the largest amount of money, $63,000 having been collected on that work, and when the work is finished $15,000 or $18,000 more will have been collected. This represents one of the most valuable single contributions. The reason why it has been so well supported is that not only the steam-turbine manufacturers but all of the public-utility people and the boiler manufacturers require good steam tables, especially in this day when the pressures are going up. For that reason we have had considerable support from all of those groups. Most of the work has been carried on in the Bureau of Standards and at Harvard, equally divided between college equipment and government equipment.

As to the methods used in the A.S.M.E., they are of interest to you because you are looking for a path by which you may arrive at the solution of your research problems. It seems that the first thing you can do, if you are unable to provide sufficient funds individually to do a real job on this very expensive pursuit, you will have to get together as a trade organization or through some committee organization.

After we have undertaken a project, the first thing is to make an examination of what has already been done, correlating that information, and laying the foundation for future research. For example, on fluid meters we spent nearly nine years before the first section of the report was brought out. During those nine years there was some quarreling among the manufacturers and users as to what was right and what was not right, but only $1500 had to be spent (on pulsating flow) to get out a textbook of up-to-date information on the theory of flow. After examining all of the literature, we found that most of the work had already been done. That is one way in which duplication of work may be avoided.

The method by which we function has been growing during the past 15 years. Our feeders may be the survey committees of the professional divisions, the National Research Council, or any individual member of the Society who may have a proposition to present. The subjects are brought in with full data, and a program is outlined, and reaches the Main Research Committee. We go back to the professional divisions and ask them for suggestions in the way of organizing the committee, and from that point on the committee is granted funds with which to operate, and they proceed on their own so far as possible.

The Main Research Committee is called upon to assist in the way of an occasional donation or establishing contact from one or two other sources, but generally the committee is provided with funds for laboratory work from the outside sources. The manufacturers have been the largest contributors, because in general they have been the ones who immediately benefit from the results. After this period of education has been completed there is not nearly so much difficulty in getting the money required to carry on these experiments.

With regard to a question that was raised this morning, we have 29 special committees under the direction of the Main Research Committee. Each of these committees is investigating a particular problem. About three of those committees are working on fundamental research, and about 30 per cent of them are joint committees. When we find that the problems reach out beyond the field of any one society, we immediately establish contact with the other groups.

For instance, on our Boiler Water Committee, we received assistance from the American Water Works Association and the National Electric Light Association. There are other joint committees I could mention. In every case we make an effort to tie up with all of these groups, whether they are trade organizations or not, if they have an interest in the problem. In that way we can get the largest number interested and the greatest prevention of duplication of effort. When you have two groups working on a particular problem, you get farther ahead than if you were working with only one group.

In the problems which have been brought out already in this conference, such as the fuel-oil specifications, the design of the Diesel engine, and the matter of spray nozzles, etc., you have already the mechanism available to go into this matter thoroughly if you want to make use of it.

W. F. Joachim.[3] The National Advisory Committee at its

[3] National Advisory Committee for Aeronautics, Langley Field, Va.

Langley Field laboratories has been carrying on research on the high-speed oil engine for the past six years. One of the major activities that was first developed was the committee's spray-photography equipment.

This is a parallel apparatus to the equipment that Professor Schweitzer has shown you. Instead of injecting the sprays into a pressure chamber against a swinging pendulum, the committee's apparatus has a much smaller chamber with large optical-glass windows, and pictures are taken of the sprays on photographic film. The apparatus may be divided into three major parts: that part which produces the illumination, the part which produces the sprays, and the camera. The illuminating apparatus consists of 25 high-tension condensers, charged by a transformer of 2-kw. capacity to about 40,000 volts. These condensers are discharged through a rotary distributor disk about 30 in. in diameter, at the rate of from 2000 to 4000 discharges per second. The electric sparks, which are about 1 in. long, occur in a reflector and are focused upon the spray chamber.

The sprays are produced coincidentally with the discharge of the electric sparks, so they are illuminated at a very high speed. The camera is on the opposite side of the spray chamber from the reflector and consists of a light tight-box containing a film drum about 12 in. in diameter, driven by an electric motor at high speed. As the sparks pass between the electrodes in the reflector they illuminate the spray nozzle first, then the tip of the fuel jet, then the fuel spray as it grows and develops, through the cut-off of the spray, and then its final development and dispersion. These spray images are caught by the film on the rotating film drum. The nozzle and fuel sprays are very well defined, even though the sprays themselves may be moving at a rate of 400 or 600 ft. per sec. and the film may be traveling at the rate of 200 ft. per sec.

With this apparatus the committee has studied the effects of injection pressure on the fuel, the effects of air pressure up to 600 lb. per sq. in. in the chamber, the effects of various nozzle designs, the effect of injection turbulence, injection tube length and diameter, the effect of various gases, various fuels, and so forth.

In endeavoring to point out some of the things that have occurred in our research activities that I believe indicate the importance of research, I want to tell you about my first attempt to design an injection valve for producing a uniformly distributed continuous spray in what might be termed a flat disk-shaped combustion chamber.

Realizing that a very fine atomization was necessary for high-speed operation, I did not want to use sprays from round orifices, and I attempted to design injection valves using annular orifices and centrifugal force. I felt that if an injection valve could be designed to produce such a high centrifugal force that the fuel would be thrown outward in a horizontal plane, practically perpendicular to the axis of the orifice, we would have developed a valve very much worth while.

The centrifugal force was produced by turning multiple grooves on the end of the injection-valve stem, after carefully calculating the velocity of the fuel, which would lead the fuel into a small chamber and thence through a round hole. The final dispersion of the fuel after its exit from the hole was calculated to produce a cone with an angle of 120 deg. We tested it and it was about 110 deg. The difference in cone angles can probably be explained by the adhesion of the fuel to the surfaces, surface tension, etc. When this injection valve was placed in the spray-photography spray chamber and the injection of the fuel made in the air under pressure, the fuel spray which was just about right for injection into a flat-top combustion chamber, as viewed in the atmosphere, closed up like a rosebud at night. It was disappointing. The result of that test was that the spray was finally directed mechanically.

In some of the committee's engine work which is carried on in single-cylinder aircraft engines, using Liberty engine parts, such as connecting rods, pistons, rings, valves, etc., we have had occasion to vary the size of round orifices in a vertical disk-shaped combustion chamber in order to determine the effect of orifices on the penetration, and the effect in turn of the penetration of the jet in this chamber. The orifices used in two of the main jets varied from $^{10}/_{1000}$ in. to $^{21}/_{100}$ in. The total distance for penetration was about $4^1/_2$ in. The $^{10}/_{1000}$-in. orifice sprays did not reach the piston. The power performance was not exceptionally good. In increasing the orifice diameter the performance improved, even though the sprays actually contacted with the piston head.

Most of us have the idea that our fuel sprays should just reach the piston crown or the cylinder wall and should go no further. The writer believes that it is true with the cylinder wall, but of the piston crown, recent results have indicated it is desirable to have the spray hit the piston and then distribute itself at that point.

Professor Schweitzer's spray chamber will give you information on sizes of injection valves which the committee is not prepared to test. The committee's work so far has concerned itself with cylinders of the aircraft size, 5-in. bore by 7-in. stroke, and by carefully programming the work and carrying it on with the spray-photography equipment, using those results to construct injection valves and fuel pumps, the performance obtained on the single-cylinder aircraft engines has improved at a rapid rate.

In 1922 and 1923 the cylinder pressures in these single-cylinder units ranged from 1600 lb. to 2000 lb. per sq. in. The reason for this was that at that time the committee's spray photography was not in operation. We needed more research. In the year succeeding, the cylinder pressure was reduced, first to 1000 lb. per sq. in. and then to 800 lb. per sq. in., and during this last year we have obtained at 1500 r.p.m. a brake mean effective pressure of 100 lb. per sq. in., with a fuel consumption ranging around $^1/_2$ lb. per b.hp. and cylinder pressures as low as 550 lb. per sq. in.

When these performances are corrected to multi-cylinder engine operation, the brake m.e.p. is 110 lb. per sq. in. and the fuel consumption about 0.46 lb. per b.hp-hr. To obtain the same performance at 1500 r.p.m. as is obtained in engines around 600 r.p.m. is a considerable feat, and it could not possibly have been done without the research facilities at Langley Field and the money with which to back it up. The writer would like to say that Professor Schweitzer's equipment is capable of doing the same thing in a somewhat different way for the oil-engine industry and would like to urge that each one here avail himself of the opportunity to carefully inspect the Pennsylvania State College equipment and get behind the project.

# Diesel-Fuel-Oil Specifications

By G. H. MICHLER,[1] NEW YORK, N. Y.

*The author gives examples of the various specification requirements encountered by the oil refiners, and points out the impossibility of carrying several grades of Diesel fuel oil at distributing points which are not also refining centers. Unless Diesel engines are constructed which can operate efficiently on a standard grade of oil of broad specification, ship operators will be unduly restricted to limited points of fuel supply and may be precluded from operating in the most desirable trade services. He suggests that three specifications would be sufficient: a minimum gravity of 24 deg. A.P.I., a maximum sulphur content of 1.5 per cent, and a minimum flash of 150 deg., closed cup.*

I HAVE BEEN hoping for some time to have an opportunity to present to Diesel-engine engineers and manufacturers one of the problems facing the petroleum industry today in its endeavor to meet the varying demands made upon it for Diesel oil for the many types and makes of Diesel engines now in use. I therefore welcome the opportunity afforded to present a picture of our problems with the earnest hope that this audience may feel they are worthy of consideration and may cooperate with us, after obtaining a closer understanding of the oil-suppliers' situation, toward a simplification and standardization of Diesel-oil specifications. This cannot fail to operate to the mutual advantage of Diesel-engine designers and builders, Diesel-engine operators, and the suppliers of the fuel for these engines.

Let me say at the outset that I do not believe the petroleum industry has any clearer understanding of your problems than you have of ours. It is only by an exchange of ideas from each side, for which this meeting furnishes an admirable opportunity, that each party interested in the development of the Diesel engine can appreciate the limitations of the others.

## Growing Ascendency of the Diesel Engine in the Marine Trade

The growing importance of the Diesel engine as an economical power unit cannot be overestimated. In one of its principal fields, the marine trade, its growing ascendency over steam power plants is attested to by Lloyd's marine-construction figures for the year 1927, which reported that for the first time in history world-wide construction of Diesel ship tonnage exceeded construction of steam tonnage, the comparison being as follows:

| | No. | Steamers, deadweight tons | No. | Motor vessels, deadweight tons |
|---|---|---|---|---|
| American | 11 | 71,900 | 8 | 18,670 |
| Foreign | 364 | 1,422,000 | 277 | 1,590,848 |
| | 375 | 1,493,900 | 285 | 1,609,518 |

It will be noted that in Europe where the construction of motor vessels is considerably more advanced at the present time than in this country, motorship construction during the year surpassed steamer construction by about 200,000 deadweight tons. This represented a considerable advance in Diesel construction over 1926 in which 925,837 deadweight tons of steamers were constructed as compared to only 701,777 deadweight tons of motorships.

When we consider that the fuel consumption in these large units bears a ratio of 1:3 as compared to fuel oil burned by steamers under boilers to develop the same horsepower in comparable tonnage, the importance of the Diesel engine as a factor in conserving the future world oil supply can be appreciated. Its advantage to the operator, particularly of freight ships, on long trade routes, is decided. His fuel consumption is materially decreased, making available more space in the ship for freight-earning cargo and requiring him to make fewer stops for fueling purposes. A good illustration of this is furnished by the recent development by some shipping companies of a fast round-the-world freight service by Diesel ships which, in some instances, practically bunker for the entire round at one port.

Everything apparently justifies the operators' investment in a comparatively high-priced piece of mechanism (in this country at least), but there is, as usual, a fly in the ointment. In this case it is the various types of Diesel oil required by different engine builders, and passed on by them to operators as a basis of performance guarantees.

## Various Types of Diesel Oil Demanded

Let me cite some examples: A couple of years ago a motorship made her maiden voyage from a United Kingdom port to the United States. The following is comparison of oil supplied the vessel in the United Kingdom and oil supplied by our company at New York:

| | United Kingdom sample | New York sample |
|---|---|---|
| Gravity at 60 deg. fahr. | 26.7 | 30.2 |
| Flash, Pensky-Martens closed cup, deg. fahr. | 175 | 175 |
| Viscosity, Saybolt, at 100 deg. fahr. | 98 | 50 |
| Sulphur, bomb method, per cent | 1.34 | 0.4 |
| Carbon residue, per cent | 3.05 | 0.4 |
| Asphalt, Italian tar test, per cent | 45 | 6 |
| Ash | none | none |
| B.t.u. per lb. | 19,125 | 19,400 |
| Water and sediment | trace | trace |

At the time of delivery, our knowledge of requirements of marine Diesel engines led us to believe that the oil furnished by us was very much superior to that furnished on the other side, and we believe that most Diesel-engine manufacturers would be of the same opinion. This is apparently borne out by the specifications issued by marine-Diesel-engine builders from time to time.

In actual operation of the vessel, however, serious trouble was encountered, and all of the trouble was laid to the oil by the operators of the motorship. As an experiment, we mixed 40 per cent of a heavy residue oil with Diesel oil, which had the result of reducing the gravity, increasing the viscosity, sulphur content, and coke residue, and very materially increasing the asphalt content by what is known as the Italian tar test, also reducing the B.t.u. per lb. In other words, the oil was brought to what we consider a poorer quality and made to conform more nearly to the grade of oil delivered in the United Kingdom, which appeared to operate successfully. Whether the trouble was due to the grade of oil delivered or mechanical troubles of the engine we are not in position to say. Under any circumstances, the operators claimed that by blending what we considered an inferior oil, their troubles were overcome. This is only one illustration of the difficulties we have encountered.

## Various Specification Requirements of Ship Owners

One of the largest customers of the company which I represent who buys a considerable volume of Diesel oil for his ships at

[1] Standard Oil Company of New Jersey.

Presented at the First National Meeting of the A.S.M.E. Oil and Gas Power Division, The Pennsylvania State College cooperating, State College, Pa., June 14 to 16, 1928.

North Atlantic and U. S. Gulf ports insists on various specifications for different ships, although all of them were engined by the same company in Europe. For some of his vessels he requires a maximum sulphur content of 0.75 per cent, and a minimum A.P.I. gravity of 26 deg. For other vessels he limits the maximum sulphur content to only 0.5 per cent and stipulates that gravity shall not be below 27.5 deg. These specifications are drawn in accordance with the guarantee of the engine builder. Vessels with engines of the same make have operated successfully for years on the West Coast on an oil with a sulphur content of over 1 per cent, and gravity at times as low as 24 deg. For several years our company had a contract with another ship operator who required Diesel oil of a minimum gravity of 33 deg. A.P.I. Builders' specifications were again given as the reason.

Another of our contract customers requires the following minute specifications of Diesel oil for delivery to his ships:

| | |
|---|---|
| Viscosity at 100 deg. fahr. Saybolt Universal, sec. maximum | 100 |
| A.P.I. gravity, deg. | 25+ |
| Flash point, Pensky-Martens closed cup, deg. fahr. | 150+ |
| Ash, per cent, not more than | 0.05 |
| Hard asphalt, insoluble, per cent, less than | 1 |
| Coke, per cent, not exceeding | 1.5 |
| Hydrogen, per cent, not less than | 11 |
| Carbon, per cent, not less than | 86 |
| Oxygen, per cent | none |
| Cold test, deg. fahr., not more than | 46 |
| Water, per cent, not to exceed | 0.5 |
| Sulphur, per cent, not more than | 1 |
| B.t.u. per lb. | 19,000+ |

It is natural that Diesel-engine builders should wish to insure a supply to their engines of fuel oil ideally suited for their best performance. It is further natural that in the course of evolution, through which any new type of machinery must advance toward perfection, there should be a wide variation in the ideas of different manufacturers as to what constitutes a suitable fuel for their particular engine. One present phase of evolution is that manufacturers are endeavoring to construct engines which will operate on heavier oils. In doing this it seems that these engines will not operate on lighter grades of oil such as are considered more desirable for other engines. Each manufacturer seems to have a different idea of the grade of oil required for his particular engine. Sulphur is sometimes blamed for all troubles encountered, and some manufacturers, as mentioned previously, are requiring that oil should be used containing not more than 0.5 per cent of sulphur. It is our view that to limit sulphur to this low percentage is unnecessary, and further it is our view that a great many of the other specifications demanded are unnecessary. During the early period of development of the Diesel engine, such varying requirements in fuel specifications were perhaps excusable. Is it not a fair question to ask today, however, whether the Diesel engine has not developed to a point where such minute and variable specification restrictions are no longer either necessary or desirable? Their continuation can have only one result, and that an unfavorable one, to the further progress of the Diesel engine: higher cost of Diesel fuel oil.

### Diesel-Oil Problems of the Petroleum Industry

To clearly appreciate the reason for this statement requires an understanding on the part of the engineering fraternity of the problems of the petroleum industry.

In a great many cases the exacting specifications now required cannot be met, or if they can be met the oil can only be delivered from refining centers, as the specifications demand running a special batch of oil, carrying it in separate tankage, and delivering through clean lines or barges so that the oil will not become contaminated with what has heretofore been considered a standard grade of Diesel oil. Take, for example, unnecessarily restrictive sulphur limitations. They may require the fuel-oil supplier to manufacture a special batch of Diesel oil from low-sulphur crudes, which either may not be available when delivery is wanted or else are considerably more expensive than crudes of a higher sulphur content that would be suitable for the manufacture of Diesel oil of a more liberal sulphur specification.

### Impossibility of Carrying Several Grades of Oil at Points Not Refining Centers

We do not believe that consideration has been given to the fact that it is impossible to carry several grades of oil at distributing points which are not refining centers. If the oil industry attempted to do this it would have to invest millions of dollars in increased tankage in order to carry separate grades of oil at different points where there might only be a demand for the special grade required once a year. It will be readily seen that this does not fit in with refinery operations, nor does it fit in with tank-steamer deliveries. It is of course impractical to carry several different grades of Diesel oil on a tanker making delivery from a refinery point to an oil-distributing station. Imagine a distributing station on the Atlantic seaboard where storage sufficient for the volume of business done is replenished by tanker deliveries from the nearest refining center. Imagine at the same time having contracts with shipping interests, one of which calls for a minimum gravity of 33; another of which prefers 24 gravity and does not under any circumstances want to exceed 28; one of which has a sulphur limitation of 1 per cent; another sulphur maximum limitation of 0.5 per cent; and still another which has ten or a dozen minute restrictions with reference to viscosity, ash, hard asphalt, coke, hydrogen, carbon, oxygen, etc. Suppose, further, that against each one of these contracts only one vessel per year calls for bunkers; a tremendous investment would have been made for separate tankage, lines, and transportation from the refining point against each of the contracts made, and perhaps one delivery of, say, 2000 barrels of each grade would represent the return on the investment.

We feel that Diesel-engine manufacturers overlook the fact that crude petroleum is produced in a great many sections of the world. All of these crudes vary in their characteristics. In the United States foreign crudes will be received from Peru, Mexico, Colombia, Venezuela, Trinidad, or the Argentine, and in addition to these foreign crudes Atlantic Coast refineries may be receiving crudes from Pennsylvania, Illinois, Kansas, Arkansas, Oklahoma, Wyoming, Texas, or California. Some are primarily asphaltic-base crudes, some naphthene- and some paraffine-base, and all vary in their other characteristics. Furthermore there may be some variance in crudes from different sections of these various producing divisions.

Consider for a minute the operation of an oil refinery on the Atlantic seaboard. It will receive daily by pipe line and tank steamers crudes of widely varying characteristics from different parts of this country or imported from other countries. The problem is to extract from these crudes various grades of finished products, aviation naphtha, gasoline, lubricating oils, greases, wax, kerosene, gas oil, Diesel fuel oil, light fuel oil for metallurgical work, bunker C fuel oil, and asphalt, not to mention a large assortment of specialties. You can readily appreciate the number of stills, lines, and tanks required to handle such a volume of products from different kinds of crude oil. Let us go further still and imagine the result of a dozen or more of different sets of specifications being required for each one of the long list of finished products—the result is obvious. It means multiplying refinery equipment and expense to a point beyond all reason. The cost of finished products must compensate for the unreasonable extension of equipment. It is perfectly true that there are

a great number of different grades of lubricating oil, which is of necessity a highly specialized product, but you do not buy lubricating oil at a Diesel-fuel-oil price.

### Considerable Latitude Required in Drawing Diesel-Oil Specifications

It is therefore clear that there must be considerable latitude in drawing up Diesel-oil specifications. An exacting specification drawn up to meet a Diesel-engine fuel oil that might be made from Mid-Continent crudes would quite likely not be met with Diesel-engine fuel oil produced from California, Venezuela, Mexico, or Texas crudes, nor could such a specification be met by refiners who are running a great number of mixed crudes. In other words, if an attempt is made to segregate crudes to produce Diesel oil only from a selected crude, the cost of the product would be high.

As we see it, the successful development of the Diesel engine is dependent on a supply of Diesel-engine fuel oil at the lowest possible price. The main obstacle in the future to a reasonable price is the lack of a standard Diesel-oil specification with sufficient flexibility to permit refiners to utilize crudes from various sources and to carry one grade of Diesel oil in tankage at different points. Unless this is done, the future progress of the Diesel engine is going to be very materially handicapped. This handicap will be twofold: in the first place, the cost of manufacturing, handling, and storing a variety of different grades of Diesel oil may cause the price to mount to a point where it would destroy the economy which rightly belongs to the Diesel engine due to its low fuel consumption. In the second place, unless Diesel engines are constructed which can operate efficiently on a standard grade of Diesel oil of broad specifications, ship operators will be unduly restricted to limited points of fuel supply. This feature might very easily preclude their operation in the most desirable trade services.

From the standpoint of the oil companies the question of specifications is considerably simplified if they are limited to three: minimum gravity, sulphur content, and flash. With regard to the first, it is our feeling that a minimum gravity of 24 deg. A.P.I. should be generally satisfactory. We believe that a maximum sulphur content of 1.5 per cent should be acceptable. Minimum flash of 150 deg. closed cup has always been the standard. We should welcome an expression of opinion from you as to the suitability of these specification limits, and whether you do not feel that further restricting specifications are unnecessary.

I know you are all interested in the advancement of the Diesel engine. I am sure you agree that that advancement depends upon a suitable future supply of Diesel-engine oil at a reasonable price. I am equally sure that you have not been in a position to realize the fact that varied and restrictive specifications present a formidable obstacle to low-priced Diesel oil. I have endeavored in what I have said to show you that that is the case. The more liberal the specifications of oil demanded for Diesel engines, the greater the security of an adequate supply of fuel oil for them at a reasonable price in the future. To this extent the success of the Diesel engine is in the hands of its designers and builders.

## Discussion

J. J. Broshek.[2] The Navy is a large consumer of Diesel oil, principally as fuel for the engines of submarines, of which there are about eighty in service at the present time. Contracts for the oil are made by the Bureau of Supplies and Accounts in Washington, and all of it is required to be in accordance with Navy Department Specification 7-0-2 of May 1, 1925, only one grade of fuel oil for the Diesel engines of submarines being provided for.

General requirements in the specifications provide that the fuel shall be a hydrocarbon oil, free from grit, acid, and fibrous or other foreign matters likely to clog or injure the burners or valves, and, if required, shall be strained by being drawn through filters of wire gauze, 16 meshes to the inch. The oil must comply with the following five detail requirements:

1 The flash point shall not be lower than 150 deg. fahr., Pensky-Martens closed tester
2 Water and sediment combined shall not amount to more than 0.5 per cent
3 The total sulphur content shall not exceed 1.50 per cent
4 The viscosity shall not be greater than 200 sec. at 32 deg. fahr. by the standard Saybolt Universal viscosimeter
5 The ash shall not exceed 0.1 per cent.

The requirement of 150 deg. fahr. as the minimum flash point is standard for all grades of fuel oil used in the Navy except in the case of very heavy oils, when the flash point is required to be not less than the temperature to which the oil must be heated to give a viscosity of 8 deg. Engler or 30 sec. at 150 deg. fahr., Saybolt Furol.

A limit of 0.5 per cent of water and sediment is believed to be ample. This item is not included in the three specifications which are recommended by Mr. Michler, but it is considered a desirable one.

The sulphur content has been the subject for much discussion and thought, and only as recently as 1924, one year before the specifications now in use were issued, a sulphur content of not in excess of 1.0 per cent was required for Diesel oil; but oil with this comparatively low sulphur content was hard to get at a reasonable price, so the limit was raised to 1.5 per cent. There was a general belief that sulphur in the fuel had a decidedly corrosive effect, but with existing designs of engines there has been practically no complaint from vessels on this score. Examination of a large number of submarine engines has shown no pitting or corrosion that could be attributed directly to sulphur in the fuel.

Fuel for the Navy, whether Diesel or bunker oil, is never purchased under a gravity specification; the limiting factor for naval requirements is viscosity. For use on submarines the oil must flow readily even at a low temperature, and this quality cannot be covered by a gravity limitation since oils of the same gravity may have entirely different viscosities. At the fuel-oil testing plant in the Navy Yard at Philadelphia, there were recently tested two oils with identically the same gravity, 18 deg. B.; one, an Asiatic petroleum, had a viscosity of 4 deg. Engler at 90 deg. fahr; the other, an East Coast oil, had a viscosity of 4 deg. Engler at 189 deg. fahr.

The ash content is specified at less than 0.1 per cent and is kept low, because if present in any quantity it might cause serious injury to the working parts of the machinery. With the Diesel oils ordinarily supplied this requirement should present no difficulty.

To insure that the specifications are complied with, three representative samples are taken from each lot; one sample is tested by a Navy inspection office, one is for the contractor supplying the oil, and the third is for reference to the Bureau of Standards in case of a dispute as to the quality.

The Navy has had no trouble in obtaining fuel meeting the requirements of these specifications at a reasonable price; contracts are usually made for six months or a year and provide for deliveries of estimated quantities at certain designated ports both on the East and West Coasts.

[2] Commander U. S. N., Navy Yard, Philadelphia, Pa.

O. H. Weise.[3] The author has indeed rendered a splendid service in bringing to the attention of the Diesel-engine builders the lack of standardization of Diesel-fuel-oil specifications, and in the construction of engines which should burn the same qualities of oil so as to avoid the necessity of storage of various grades of fuel oil suitable for Diesel engines.

The shipowners operating Diesel-engined vessels have interests common with the petroleum industry in desiring a standardization of Diesel-fuel-oil specifications and should welcome the formulating of such a standard in order to insure the procuring of suitable oils at a more reasonable price, which such standardization would no doubt bring about. At the present time every Diesel-engine builder has specifications for fuel oils which in many instances have been found to meet the requirements of their engines, and in other cases grades of fuel oil have been arbitrarily selected which would be more beneficial to the life and operation of the engine, thus avoiding complications which would necessitate costly experimental work in developing fuel-injection systems in order to make their engines suitable for burning a heavier grade of fuel oil. Such divergence of opinion of Diesel-engine builders has brought about a condition which requires a considerable variation in the qualities of fuel oils required for Diesel engines, and which burdens the purchasers as well as the petroleum industry.

The above statements are borne out by the examination of the questionnaires submitted by engine builders with their bids on main and auxiliary engines recently opened by the Shipping Board.

The lowest grades of fuel which the various builders claimed they could use in their engines successfully varied between the following characteristics:

| | |
|---|---|
| Viscosity, Saybolt Furol, 60 deg. fahr. | 56 to 1000 |
| Acid | 0 to $2^1/_2$ per cent |
| Sulphur | 1 to 4 per cent |
| Ash | 0 to 1 per cent |
| Residue | 0.05 to 35 per cent |
| Coke | 0.20 to 5 per cent |

It may be of interest to know what fuels were used on the tests of the main and auxiliary engines built for the Shipping Board during the initial program which is tabulated below:

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Baumé at 60 deg. fahr. | 26.8 | 24.9 | 21.1 | 25.6 | 20.3 | 19.70 |
| Viscosity, Saybolt Furol, at 77 deg. fahr. | 46.5 | 53.0 | 50.8 | 19.0 | 67.2 | 202.0 |
| Carbon, per cent | 86.5 | ... | 85.6 | 85.8 | 87.6 | 86.99 |
| Hydrogen, per cent | 12.4 | ... | 11.99 | 12.5 | 11.6 | 11.43 |
| Sulphur, per cent | 0.66 | 0.76 | 2.53 | 1.06 | 0.40 | 1.12 |
| Oxygen and nitrogen (Diff.) | 0.28 | ... | 0.95 | 0.62 | 0.38 | 0.46 |
| High H.V. | 19,374 | 19,180 | 18,780 | 19,164 | 19,002 | 18,954 |
| Low H.V. | 18,188 | 18,020 | 17,706 | 18,071 | 17,917 | 17,883 |
| Average temp. of fuel during test, deg. fahr. | $62^1/_2$ | 145 | 140 | $73^1/_2$ | 88 | 72 |

In establishing a specification for Diesel-engine fuel oils, the lowest quality should be established so that the owner of a Diesel-engine plant could obtain the advantage of low-priced fuels, which should enhance the economic value of the Diesel engine.

In the case of marine Diesel engines, the chief saving lies in the annual fuel bill, and therefore the lowest quality established as satisfactory would give the greatest saving, which naturally is of paramount importance. There is also the advantage that by setting a fairly low limit on the quality of fuel oils, the engine builders would be encouraged to strive toward the construction of engines which would meet conditions required for the use of this grade of oil, which would also be a stride forward toward the development of the Diesel engine.

The author did not mention viscosity, which appears to be the chief characteristic of fuel oils giving the engine builders concern. These oils must have a viscosity low enough to readily flow to the fuel pump and through the small piping between the fuel pump and fuel valves, so that if the highest viscosity permissible at the fuel pump is established, there is little reason to consider gravity.

The author's selection of the maximum sulphur content of $1^1/_2$ per cent seems reasonable, and in addition to the foregoing characteristics, ash and coke should be limited, as coke has a tendency to gum up the cylinders and piston rings, while ash, if found to any great extent, will have a detrimental effect in causing excessive liner and piston wear.

It has been rumored that one of the Standard Oil groups in the East has been carrying on experiments to develop a Diesel oil by treating ordinary bunker C by some process in order to reduce its viscosity, and it would be of interest to have the author give such information as he may be willing to disclose relative to the success that has been attained with these experiments, and also how the cost of this oil would compare with that of ordinary boiler fuel.

[3] U. S. Shipping Board, New York City.

Ernest Nibbs.[4] Many expert chemists who have grown up with the oil industry frankly state that they know comparatively little about the complex structures forming what are known as crude oils. In refineries, similar processes on different crudes result in differing products; different processes on similar crudes also differ in the results; and similar processes, except for small changes in temperatures and pressures, will produce different results from similar crudes. When it is considered that oil companies endeavor to market all their product, adjusting their processes best suited both to their raw material and the market of the moment, it is not to be wondered at that the Diesel-engine manufacturer as well as any other consumer receives a consideration exactly in proportion to the value of the oil company's product for which he provides a certain market.

Meanwhile the Diesel builder produces a Diesel engine. It is tested thoroughly, marketed, and after a time the customer comes along and says his engine will not burn the only oil he can obtain in such and such a place. Sometimes he says, "I can get burnable fuel, but I want to use the cheapest possible." Another says, "The engine must use oil picked up at any bunkering port in the world." And so the engine builder responds, and tests various kinds of fuel procured from many various fields, only to find that some unexpected results occur. By experience he finds that oils above a certain viscosity number have to be heated, and that goes into his specification; other oils, even if heated, give him trouble with wax in spray valves or carbon in valve passages; others seem to delight in depositing a sticky, resinous, asphaltic substance on and behind piston and rings, while some cause steel and iron parts to corrode extensively. Very naturally he specifies characteristics which he has found will give good service in his engines; but as all engines are not alike, as many fuel specifications exist as there are engines.

Mr. Michler proposes three qualities only: maximum specific gravity, maximum sulphur, and minimum flash point. With numbers 2 and 3 I am in agreement; the third for the reason that the insurance societies insist on a minimum flash point of 150 deg. fahr., and this requirement is of the nature of one imposed on two parties by a third party; the second, because up to 1.5 per cent sulphur my experience leads me to anticipate no trouble; but the first does not appear to me to be sufficiently fundamental or embracing.

Will specifying specific gravity alone or in combination with maximum sulphur and minimum flash point prevent an oil's being

[4] Chief Engineer, New London Ship & Engine Co., Groton, Conn.

supplied that will not flow at ordinary temperatures? Will it limit the amount of water that may be in the form of a mixture or an emulsion? Will it prevent too great a proportion of bottom ends being blended with a high-grade distillate? Will it insure a fuel that will not settle out into its original parts when in storage? I do not think it will, and yet all these points are important. Consider tar, asphaltum of the hard and soft varieties, resins, waxes, and coke; think of the various tests and names of the tests designed to define these constituents; the Italian tar test, which I confess was first called to my notice by Mr. Michler; the test by the Nolde method; the California tar test; the various degrees of purity of the petroleum ether used in dissolving the tar content, and likewise that of the benzine also used as a solvent. Therefore the first step to any fuel specification is to further standardize nomenclature of the various tests. Many of these are standardized already, the A.S.T.M. having done good work in this connection, but those in connection with tar and asphalt need some attention. Likewise the terms "tar," "pitch," "asphaltum of the hard and soft kinds," "asphaltic residues," etc., require definition and general adoption. After this has been done, the hardest part remains, viz., specifying "Diesel fuel" that will be fair to all engine builders, to the operators and owners of engines, and to the oil producers. It involves many things: whether the specifications are to be international and (or) national, national and (or) regional; whether the fuel to be specified is intended to be consumed by marine or stationary internal-combustion engines where ignition is by heat of compression only, including hot-bulb engines, or consumed by engines excluding these latter; whether the classes of fuel, if classes there be, shall limit in both directions or only one.

Here are the analyses of two different fuel oils, both of which are supposed to be suitable for Diesel engines (the latter of which will be pumped to a ship whether bunker fuel A, B, C, or Diesel oil is ordered):

| | | |
|---|---|---|
| Specific gravity | 0.9371 | 0.9395 |
| Baumé | 19.5 | 19.1 |
| Flash | 235 deg. fahr. | 220 deg. fahr. |
| Viscosity at 77 deg. fahr. Saybolt Universal | 950 sec. | 93 sec. |
| Viscosity at 122 deg. fahr. Saybolt Universal | 250 sec. | 50 sec. |
| Carbon residue, Conradson | 6.02 per cent | 1.50 per cent |
| Asphaltic matter, A.S.T.M. precipitation No., using petroleum ether | 20 | 4.8 |
| Water (distillation method) | 0.70 per cent | 0.42 per cent |
| Remainder after distillation by Engler method up to 620 deg. fahr. | 68 per cent | 42 per cent |
| Low heating value | 17,805 B.t.u. | 17,264 B.t.u. |
| Ultimate Analysis (percentages) | | |
| C | 84.76 | 87.34 |
| H | 11.64 | 11.04 |
| Sulphur | 0.83 | 0.37 |
| Ash | 0.06 | 0.02 |
| N | 0.48 | 0.06 |
| O and undetermined | 2 23 | 1.17 |

Both are not really good. They can be utilized, although the first requires heating to handle properly, and the second, though very fluid, has some high-molecular-weight compounds, probably aromatics, that are hard to burn.

The M.A.N. Company consider, in general, that viscous oils should be burnt with a small charge (about 5 per cent) of a superior grade of fuel; if this be not done, then in time the operator will pay excessively for wear and tear and maintenance due to unburnt fuel at light loads, besides having paid more in the first case for extra installation features, comprising special heaters in tanks, supply-line pumps, pipes on engines, special cleaning and filtering arrangements, and stowage for different fuels. Simplicity and reliability are the great needs of today in the marine world; many intricacies and complications are unavoidable, and we should therefore avoid those we can, especially in modern ships which can carry sufficient fuel for round-the-world trips from selected ports.

In order to present an alternative to Mr. Michler's proposal I submit the following as reasonably insuring a fuel that I believe would give satisfaction for guarantee purposes and continued operation for marine and stationary installation without pressing unduly hard on oil refiners for output or consumers for cost; and I would point out that specific gravity is not included in the requirements.

| | Marine | Stationary |
|---|---|---|
| Flash point, insurance-company requirement, deg. fahr., not less than | 150 | 150 |
| Heat content, operators' requirement, B.t.u. per lb., low heating value, minimum | 17,500 | 17,500 |
| Water content, operators' requirement, per cent, not over | 0.05 | 0.05 |
| Viscosity, operators' and builders' requirement, Saybolt Universal at 70 deg. fahr., not over | 200 sec. | 200–700 sec. |
| Sulphur content, operators' and builders' requirement, per cent, not over | 1.5 | 1.5 |
| Distillation, test builders' requirement, remainder after heating to 660 deg. fahr., per cent, not more than | 40 | 60 |
| Coke, builders' requirement, Conradson test, per cent, not over | $2^1/_2$ | 5 |

The engine builders are just as keen as the oil producers and engine operators to combine and specify a Diesel fuel such that all three industries may be run on a basis which will permit them all to obtain a fair return for their labor.

J. W. Morton.[5] There are two methods for utilizing liquid fuels for the generation of power: either the engines are adapted to the fuels, or the fuels are adapted to the operations of the engines. Sustained efforts are at present made in both directions, but whereas up till now engineering has been principally concerned with the first-named method, the oil industry has lately commenced to advance along the second line of procedure. For the Diesel engine, however, the results of these efforts are as yet insignificant.

I fully agree with Mr. Michler that an endless number of fuel-oil grades are just as perplexing to the Diesel-engine designer as it is for the oil refiner to have to furnish a special grade of fuel for every motor vessel in port.

For large horsepowers, two means are at hand for the designer: either increase the number of cylinders for a given bore, or increase the bore for a given number of cylinders, in order to obtain the desired horsepower. The shipowner is especially interested in smaller weight and space, resulting in lower first cost and larger-cargo earning capacity. The designer is interested in his cylinder dimensions, whether he can satisfactorily and completely burn his fuel-oil charge. The operating engineer is generally interested in the simplicity of his engine or engines, so that they will burn almost any kind of oil without changing all his valve settings, heating the oil, etc. Thus a uniformity in Diesel-oil specifications is a factor that interests more than one party.

I do think it is wrong for any builder to specify a certain grade of fuel oil; first, because the engine should be built so as to take care of a certain fluctuation in fuel Baumés, and secondly, it involves storage of maybe just as many grades of fuel oil as we have engine builders. With the present-day non-corroding steel

[5] Camden, N. J. Mem. A.S.M.E.

suitable for valves, I do not think sulphur plays such an important role that it is necessary to restrict its limit. I agree with Mr. Michler that a Diesel engine should more or less be able to "digest" all kinds of "food," within certain limits of course. Once, however, the engines are out of the hands of the builder, it is principally a question for the shipowner, as the real problem is one of upkeep, maintenance, and possible delay.

So far, certain regulations have been laid down regarding oils, and they have been divided into more or less useful and serviceable fuels. But the present aim of Diesel engineers is to build engines in such a way that all liquid fuels, including the most inferior and especially residues from the oil industry, may be used without any particular chemical or physical preparation. And this feature is responsible for the high degree of economy of the Diesel engine.

A preliminary condition for the use of any liquid fuels in Diesel engines is an exact knowledge of their chemical and physical properties. Strange to say, no sufficient attention has been paid up till now to the chemical and frequently also to the physical properties of liquid fuels with regard to their applicability to various classes of internal-combustion engines, and above all to the Diesel engine.

For the chemical properties of liquid fuels with respect to their use in the Diesel engine, the following factors are of importance:

1 General chemical composition for ascertaining:
  *a* Ignition and combustion and the equipment required for same
  *b* Effect of a possible presence of sulphurets on engine parts that come into contact with either the fuels themselves or with the combustion and exhaust gases
  *c* Possible effect of the presence of asphalt components, especially in case of their incomplete combustion
  *d* Effect of the presence of free carbon.
2 The ash contents, i.e., purely inorganic incombustible combinations or incombustible residues of salts from organic acids which adhere to the engine parts after combustion and cause wear and tear.
3 The heating value for approximately judging the type of fuel and determining the consumption and thermal efficiency.

Of the physical properties of liquid fuels the following are important:

4 The specific gravity, for an approximate estimate of the fuel and heating value and for determining the space required for fuel consumption and fuel requirement.
5 The flash and the combustion point, for an estimate of the fuel, the danger of fire and the requirements for storing.
(Points 4 and 5 do not concern the work of the engineer.)
6 The boiling curve, for ascertaining the composition in quality and quantity of the boiling points of its various components.
7 The viscosity at various temperatures, for ascertaining the degree of fluidity and the contrivances necessary for the feed and conveyance to and within the engine and for determining atomization by air or mechanical pressure into the combustion chamber.

As regards the technical treatment of oils, to this must be added the presence of water and mechanical impurities, which can be reduced to the lowest possible minimum for permanent work by separation, evaporation, or filtering devices.

The burning of heavy oils in an oil engine is a point of great interest. It is true that solid impurities may be fairly readily separated from the oil by mechanical means such as filters, settling tanks, and centrifugal separators; but it is the hard asphaltum case formed during the combustion that is the troublesome element. Hard asphaltum can be completely burned and is burned in some oil engines, all that is required being sufficiently congenial conditions of temperature and time coupled with sufficient air. The secret of burning asphaltum is to obtain as perfect combustion as possible. The indication of good combustion is low fuel consumption on an i.hp. basis, and generally speaking the engine with the lowest fuel consumption per i.hp. will most readily burn hard asphaltum. The fuel-injection system associated with the lowest fuel consumption on an i.hp. basis will generally be the system most suitable for using boiler oils with hard asphaltum content; but at the present day there seems to be little to choose between the best systems of either air or mechanical injection as regards fuel consumption per i.hp. Obviously, however, the engine with the lowest consumption per b.hp. will burn a minimum of oil and therefore is subject to a minimum of abrasive matter in the oil. This latter may appear unimportant at first sight, but it must be remembered that there are well-known Diesel engines burning 0.44 lb. per b.hp. and others burning 0.36 lb. per b.hp. under service conditions, a difference of 25 per cent. It is here that some solid-injection oil engines will show a distinct superiority.

Broadly speaking, therefore, it may be said that any contrivance or construction, such as improved shape of combustion chamber, which will tend to reduce the fuel consumption will also tend to reduce the formation of asphaltum coke. The foregoing is an illustration of the necessity for obtaining the best possible fuel consumption not only on the grounds of economy of fuel but also because it means perfect combustion with consequently improved operating conditions of the cylinder parts.

Most of our fuel-oil specifications are incomplete, I think. The more readily the heat units can be converted into work, the higher the price that can be paid for the fuel. The connection or ratio between the hydrogen and carbon atoms in the fuel oil is a good measure for its suitability in oil engines, but these are generally omitted in the ordinary specifications submitted when bunkering. The hydrogen content is a direct measure of the formation of a volatile "oil gas," assured by the great heating-up of the oil. The more susceptible the oil is to formation of this gas, the better it is suitable for oil-engine service.

This ratio, as specified by some well-known European shipowners, is expressed by the percentage of the carbon and hydrogen atoms combined in the fuel, i.e.,

$$\frac{\text{H}}{\text{C}} = \frac{\text{Per cent of H in oil} \times 12}{\text{Per cent of C in oil}}$$

The best all-around results are obtained when this ratio is as near as possible to 2, and it should not fall below 1.6.

The use of "boiler oil" for oil engines is principally a question for the shipowner, as the real problem is one of upkeep, maintenance, and possible delay. Oil engines can be run on boiler oil satisfactory if care is taken to rid the oil of water, sand, and other earthy matters by heating and centrifugal force. The heating is also necessary to enable the oil to be pumped and to permit of proper atomization, and excepting for a slightly higher fuel consumption, it is, so far as running is concerned, a perfectly good oil to use.

Both ash and hard asphaltum are very undesirable and must be avoided on account of the abrasive action within the cylinder, which spells "repairs," and it resolves itself into an economic question whether the saving in fuel cost warrants the greater detention and repairs. Whatever policy is adopted, it is certain that all motorships should be capable of burning oil fuel in the event that Diesel oil is not available at some bunkering station.

It is interesting to note what the author says about the im-

portance of the sulphur content of the oil. Where damage has occurred, it might have been caused by other constituents of the oil. It is reasonable to suppose that sulphur could not form sulphuric acid within the cylinder because of the temperature's being too great.

I think I am right in quoting that from the separation of crude oil 15 per cent is classed as gas oil and 45 per cent as boiler oil. The latter percentage is sure to increase at the expense of the former through the ever-increasing demand for the lighter distillates, particularly gasoline and thus we come to the crucial question: What is a shipowner to do in a few years' time with an engine which is restricted to the use of an engine oil that is difficult to obtain? Builders must prove to owners and superintendents that the use of boiler oils does not necessitate repairs if the oil is properly rectified.

The ash content in oil used in Diesel engines should be as low as possible, since ash causes wear on the cylinder liners and piston rings. A figure of 0.05 per cent should never be exceeded, and this is higher than desirable. In a few motorships boiler oil is now being exclusively employed for the Diesel engine, and the best results appear to have been achieved when arrangements are made for purifying the oil by means of centrifugal separating machines. The main object of their employment is the elimination of all water (which is less easy of separation in settling tanks than is the case with Diesel oil), as well as the ash content so far as possible, together with mechanical impurities. In all cases where boiler oil is employed it must be heated by steam coils in the tanks or by other means, while steam heating should also be provided in the gravity tank. The centrifugal machines are comparatively small plants driven by electric motors (or steam turbines) at a high speed of rotation. It may be estimated that about 50 per cent of the ash content in the oil can be removed by centrifuging, while the water can be totally eliminated. Asphaltum is not removed by passing the oil through a centrifugal separator, but this has no detrimental influence in the Diesel-engine cylinder.

The flash point at which oil can be carried on motorship has been reduced to 150 deg. fahr., so that ships may bunker at practically any port they like to visit. Settling tanks should be high and of small horizontal area and provided with heating coils fitted vertically for about two-thirds of the height of the tank to insure rapid and uniform heating of the whole of the oil in the tanks. The heating surface necessary is approximately 2.5 sq. ft. per ton of tank capacity. If viscous oil is likely to be used, heating coils should be fitted in the main fuel tanks. The heating surface necessary is about 0.7 sq. ft. for deep tanks and 1.5 sq. ft. for cellular double-bottom tanks per ton of tank capacity.

Chemists and engineers, by the help of analysis of deposits in the cylinders and exhaust passages and by signs of wear and tear obviously resulting from the use of the fuel employed, have been able to determine the constituents forming the oils which are responsible for these undesirable manifestations, and as a result of this experience are now able to prepare specifications of oils suitable for use in Diesel engines; but since these cannot be had at every bunkering station, their use is very much restricted and the importance of such specifications is somewhat nullified, and as already said, a broad specification should be adopted, sufficient only to exclude oils which would be liable to cause danger or detention, etc. to the ship, should an unsatisfactory oil be bunkered.

To summarize conclusions: Oil for marine purposes has come to stay; coal, aided by the as yet undiscovered perfect condenser tube which will permit the use of water-tube boilers with really high pressure, may still put up a good fight. The itinerary which a ship must follow is a factor in determining the most suitable machinery, but is lessening in importance as the provision of oil increases in those countries which do not produce oil. Specifications will help us to realize what we want, but will not enable us without experience of similar oil in similar engines to indulge too freely in prophecy. It should warn us off the rocks of ash and hard asphaltum, which cause wear and low hydrogen, which means low efficiency. More economical use must be made of existing supplies. As engineers we are equally ready to build and to operate with equal technical efficiency steam engines or oil engines, and any system of transmission of power, mechanical, electrical, hydraulic, or Magnus currents, which may appear most suitable to the business in hand. But commercial efficiency as between ship and ship may vary very widely with the various types of machinery, and it is on the commercial efficiency of our gear that we must rely for our future successes.

T. B. Danckwortt[6] and M. S. Reynolds.[7] The difficulties encountered by the petroleum industry in meeting the varied demands for Diesel-engine fuels have been presented by Mr. Michler in a very clear statement, with which we are in full agreement, as Atlantic Seaboard and Pacific Coast conditions with regard to facilities for fuel distribution are practically identical. Because of the fact that many Diesel engines are manufactured on the eastern coast, and hence designed with the use of eastern fuel oils in mind, we have encountered some difficulties in the application of western fuel oils to Diesel-engine operation which would be of general interest. Until a few years ago the problem of obtaining suitable fuel for Diesel engines was a simple one, but the enormous automotive-industry demand for gasoline has resulted in changed refining conditions so that the lighter grades of gas oil are no longer available in as large quantity for Diesel-engine use. The increased number of Diesel engines operating has also been a factor. The situation has become further complicated by the advent of a new type of engine, the high-pressure solid-injection type, some forms of which are very susceptible to slight variations in the physical characteristics of the fuel used. The essential requirements for the complete combustion of fuel of any type are sufficient oxygen, time, and initial temperature, and for optimum operation these factors must be combined properly by the correct and timely distribution of the fuel spray which has a penetration ability conforming to the requirements imposed by the density of the air, the shape of the combustion chamber, and controlled air-turbulence action. As a general rule, paraffin-base fuels burn somewhat more readily and rapidly than asphalt-base fuels of similar characteristics. For this reason, some of the smaller-sized engines of the solid-injection type manufactured in the East and particularly adapted to eastern fuels, give unsatisfactory performance on California fuels. On investigation, it was found in each case that the design of the combustion chamber and injection system was unsuitable for the complete combustion of California fuels, and after redesigning the engines in this respect the flexibility as to speed and permissible variation in fuel was greatly improved and in several instances the horsepower was increased 40 per cent. Because of these experiences we consider that the engine manufacturer should feel it his duty to test each new engine type and size with both paraffin- and asphalt-base fuels so as to be certain that his engine will be suitable for operation on either of these types; as well as the intermediate varieties of fuel, and hence that the purchaser will not be restricted in his choice of fuel and field of operations.

At the present time the types of Diesel engines used on the Pacific Coast and operating on California fuels are as follows:

1 *Air-Injection Type.* Air-injection engines, when properly

[6] Diesel Engineer, Union Oil Company of California, Los Angeles, Calif.

[7] Research Engineer, Union Oil Company of California, Los Angeles, Calif.

adjusted, can obtain perfect combustion with asphaltic fuel oils, regardless of gravity, viscosity, or other characteristics within wide limits. Because of the possibility of adjusting the pressure, quantity, and temperature of the injection air to obtain the best fuel economy, fuels, ranging in gravity from 12 deg. to 40 deg. A.P.I. can be used successfully in this type of engine, in spite of the comparatively short and late injection period, although in general the closed type of injection valve has somewhat better atomizing characteristics for the heavier fuels. Of course, the atomization and flame-propagation characteristics of the fuels change with the physical properties, such as gravity and viscosity, but the possibility of controlling the air-turbulence energy by the injection pressure and by the timing permits wide variation in the physical characteristics of acceptable fuels. All the conditions for efficient combustion, namely, fine and uniform atomization, air turbulence, good distribution of the fuel spray, excess air, and high compression, may be met without restricting the engine to the use of special grades of fuel.

2 *Precombustion-Chamber Injection Type.* Diesel engines of the precombustion-chamber injection type vary widely in their design and operating characteristics. In general, engines with small restrictive passages between the precombustion chamber and the main combustion chamber usually have insufficient air turbulence and heat conduction to the precombustion chamber, and this results in rapid carbonization unless the dimensions of such antechambers, including the injection device, have been developed especially for operation on our particular fuel. In other words, engines with such restrictive passages are usually poorly adapted to operation on fuels of varying characteristics.

The type of precombustion injection engine with a plain cylindrical neck between the precombustion and main combustion chambers gives a timed air turbulence before and during combustion which is adequate for the complete combustion of asphaltic fuel oils, and thus the fuel flexibility of these engines approaches that of the air-injection type. When well designed and properly adjusted, they can operate on a wide range of California fuels from 14 deg. A.P.I. up, regardless of flash point or viscosity. This system of injection is well adapted to small- or medium-sized engines of low or high compression and either two- or four-cycle. Many engines of this general type are now operating satisfactorily on Pacific Coast fuels.

3 *High-Pressure Fuel-Injection Type.* In this method of injection the fuel is forced directly into the cylinders through nozzles of very small diameter by means of high hydraulic pressures. Engines of this type are therefore very sensitive to variations in the physical characteristics of the fuel, since changes in the viscosity particularly influence the atomization and penetration characteristics of the injection spray. It is frequently found that the efficiency falls off markedly with a variation in the gravity of the fuel beyond a range of about 4 deg. A.P.I. unless the nozzle size is changed. This sensitivity toward fuel variation is marked even in the largest sizes of engine, and becomes still more serious in the small sizes. With proper adjustment of the injection by the use of suitable nozzle types, fuel pressure, and timing, the high-pressure solid-fuel-injection type of engine is well suited to Pacific Coast fuels of 24 deg. A.P.I. gravity and lighter, and the fuel economy obtained is very satisfactory. This economy, however, has been attained at the expense of sensitiveness to fuel variation, with the result that the responsibility for permanently efficient operation has been place on the oil companies instead of being assumed by the engine designers. European practice has shown that engines of the solid-injection type can be designed with greater flexibility as regards variation in fuel by giving particular attention to air turbulence with the use of open combustion chambers and high injection pressures.

A tabulation of the gravities of California fuel oils which have been used successfully in engines of different types can serve only as an approximate indication of the fuel flexibility of the various engine groups, as this flexibility depends so largely upon adjustments, loads, and minor variations in the design. However, as it may serve as a rough classification of engine characteristics with special reference to operation on Pacific Coast fuels, the following list of engine types and of fuels which have been successfully used in them is presented:

1 Air-injection engines, large and small sizes, two- or four-cycle, medium fuel pressures, uniform and controlled air turbulence, high compression; 12 to 40 deg. A.P.I. gravity.

2 Precombustion-chamber engines, two injection sprays, air or solid injection, medium fuel pressures, medium to high compression, cylindrical neck, four-cycle, controlled air turbulence; 14 deg. A.P.I. gravity and up, depending on type and size.

3 Precombustion engines, one injection spray, air or solid injection, low and medium fuel pressures, two-cycle, four-cycle, open neck, controlled air turbulence, low or medium-high compression; 16 deg. A.P.I. gravity up to gasoline, depending on type, size, speed, and load conditions.

4 High-pressure fuel-injection engines, two injection sprays, opposed-piston types, high compression, high fuel pressures, two-cycle, open combustion chamber, air turbulence; 18 deg. A.P.I. gravity and up, depending on size and speed.

5 High-pressure fuel-injection engines, one multiple-hole spray, high compression, high fuel pressures, two- or four-cycle, open combustion chamber, air turbulence; 20 to 22 deg. A.P.I. gravity and up, depending on size and speed.

6 High-pressure fuel-injection engines, one multiple-hole spray, medium or high compression, high fuel pressures, four-cycles, or two-cycle, open combustion chamber, no air turbulence; 24 deg. A.P.I. gravity and up, limited range for each engine, depending on size and speed.

7 Medium- and low-pressure fuel-injection engines with restricted antechamber, one injection spray, high compression, two- or four-cycle, cups, tubes, etc., partial air turbulence; 26 deg. A.P.I. gravity and up, depending on type and size.

What has been said about the combustion difficulties encountered on the Pacific Coast with Diesel engines of medium size applies with even greater force to the small engines which are now appearing in increasing numbers, as the sensitivity toward fuel variation increases as the combustion chamber becomes smaller, the piston speed greater, and the explosion pressures higher. Although this class of engines is still in a critical stage of development, the successful operation of foreign engines of this class on the Pacific Coast for many years has established the feasibility of building small engines which will operate satisfactorily on a wide range of fuels. Much research on engine design in relation to fuel flexibility remains to be done in order to insure a permanently cheap fuel supply to the small Diesel-engine users. To illustrate the type of service in which these engines are used and the economy which may be obtained, the following example is given:

A 2-ton Diesel boat, 21 ft. in length and equipped with a 4-hp. engine using regular Diesel fuel oil which costs $2^3/_4$ cents per gallon at Los Angeles Harbor, can run about 800 miles for an expenditure of only $1 for fuel.

From our experience with western fuels in Diesel engines, we are in complete accordance with Mr. Michler's proposal to simplify the specifications for Diesel fuels by omitting such items as carbon residue, asphalt, surface tension, etc. As long as the functions and importance of these properties have not been established by fundamental research, definite specifications for such characteristics must be considered as premature. The elaborate specifications originating with some Diesel-engine manufacturers are considered to be the result in most instances of experience in limited markets rather than of careful experimental work. Mr. Michler proposes to restrict the specifications to minimum gravity, sulphur content, and flash point. In our

opinion, the specifications for the ordinary grade of Diesel fuels (that is, excluding the heavy industrial fuel oil which can at present be used successfully in only a limited number of engines) should contain the following items:

1 Gravity. This is important as an index to the class or grade of oil, although fundamentally the property is of less importance than viscosity. A minimum gravity of 24 deg. A.P.I., as proposed by Mr. Michler, should be acceptable at the present time to both the Diesel-engine manufacturers and the petroleum industry.

2 Flash Point. As the flash point may be decreased by the presence of a limited amount of low-boiling material in the oil, it is not as significant as regards the burning characteristics of the oil as the fire point, which is the temperature at which the fuel vapor continues to burn. Until the relative efficiency of fuels of varying fire point in engines of definite compression pressure has been thoroughly determined by extensive experimental work, it is felt that no specification should be arbitrarily chosen for this property. To insure safety in handling the fuel oil, it is felt that a minimum flash point of 150 deg. fahr. in the Pensky-Martens closed cup should be specified, as has been common practice in the past.

3 Water and Sediment. This test was not mentioned by Mr. Michler, but it is felt that it should be specified to protect the buyer from the delivery of contaminated oils. An acceptable oil should have a water and sediment content not exceeding 1 per cent.

4 Viscosity. The viscosity of a fuel oil is of more fundamental importance than the gravity, as it measures directly the characteristics of the oil as regards flow through nozzles or lines. While the specification of 24 deg. A.P.I. as the lowest gravity permissible will automatically exclude oils of extremely high viscosity, it may be advisable to include a viscosity specification as a further safeguard. It is suggested that the maximum permissible viscosity be set at 100 sec. Saybolt Furol at 77 deg. fahr., following Government specifications for Navy Standard and Bunker Fuel Oil A, which, according to Technical Paper 323-B, United States Government Master Specification for Lubricants and Liquid Fuels, are both high-grade fuel oils which may be used in Diesel engines. It should be understood that this applies only to the usual grade of light Diesel fuel oil and not to heavy industrial fuel oils such as are commonly used for steam boilers but which have a restricted use in Diesel engines.

The specification for sulphur content, although not objectionable to Pacific Coast refiners if set at 1.5 per cent maximum, as suggested by Mr. Michler, is considered unnecessary, as the deleterious effect of sulphur on engine parts has been greatly exaggerated; some Diesel installations have been operating for over 20 years and under adverse conditions on Mexican fuels containing 3 to 4 per cent sulphur and still retain the original cylinders and pistons.

The limiting of Diesel fuel specifications to gravity, flash point, viscosity, water, and sediment should not work any hardship upon Diesel-engine manufacturers and should be satisfactory to the oil refiners. In considering the suggested figures for the specifications, it should be borne in mind that these may be subject to future modification as dictated by economic necessity. Even with this possibility of future change, however, the establishment of definite specifications at the present time will assist materially in the standardization of engine-fuel requirements and available types of fuel, with benefit to the engine-manufacturer and user, as well as to the oil companies, through greater economy of operating because of decreased fuel costs. The experience of our company in common with that of other members of the petroleum industry has proved the impracticability of attempting to maintain supplies of a large variety of Diesel fuels throughout the territory in which we operate, and to a lesser extent the inadvisability of supplying special fuels even to groups of consumers that happen to be located near a refining center.

As regards the future development of Diesel-fuel specifications, there is little doubt that economic considerations will force the use of progressively heavier fuels. One of the chief factors in this development is the increasing importance of gas oil as raw material for the production of gasoline by various cracking processes. The demand for gas oil as cracking stock in competition with its use as Diesel-engine fuel has already resulted in the establishment of a substantial differential in price between this commodity and heavy industrial fuel oil, and we may anticipate that this differential will tend to increase rather than decrease. The obvious remedy for the increasing cost of Diesel-engine fuels of the gas-oil type is the construction of engines which are suitable for operation on heavier oils.

One of the serious obstacles that the Diesel-engine industry must overcome is the fear of prospective purchasers that possible future increase in the price of Diesel fuel will nullify the present economic advantage of the Diesel engine. To overcome this fear, and thus insure their own future, the manufacturers must make their engines sufficiently flexible in fuel utilization to take advantage of the grades of oil economically available. The greatest increase in the use of Diesel power will come through replacement of steam plants, and when it is considered that a steam plant uses nearly three times as much oil as a corresponding Diesel plant, it is evident that such replacement will create a considerable surplus of boiler fuel. This will tend still further to increase the differential between boiler fuel and lighter fuel of the gas-oil type. With such developments, the engine that is restricted to the use of a light fuel will be penalized, and it is to the interest of the Diesel-engine industry at this time to prepare for such a contingency not only by standardizing on a simple specification for a type of fuel which will continue to be available for a considerable time, but also by developing designs of engines which are adapted to the use of heavier grades of fuel.

Harte Cooke.[8] Mr. Michler's paper gives a very interesting statement of the confusion at present existing in regard to the question of Diesel fuel oil:

I think that a general specification about as follows will cover the situation in regard to Diesel fuel oil:

Viscosity not more than 25 Saybolt Furol at 60 deg. fahr. The reason for this requirement is that fuel more viscous than this cannot be handled conveniently through piping without special provision for heating.

Flash, 150 deg. fahr. The reason for this requirement is to comply with the results of the classification societies.

Water, dirt, and foreign matter not to exceed 1 per cent. The reason for this is to prevent excessive cost in settling and cleaning the oil.

Gravity, 22 to 30 B. The reason for this is that oils heavier than 22 usually have to be heated in the system to make them fluid. Oils lighter than 30 are apt to give trouble owing to seepage past the fuel valves, causing carbonization.

In general, an oil corresponding to these specifications should be entirely satisfactory for Diesel engines.

V. L. Maleev.[9] Our experience shows that the present high-compression Diesel oil engines, particularly those equipped with the airless mechanical-injection system, can handle satisfactorily any fuel oil, provided it is clean and not excessively viscous. I agree with Mr. Michler that the specifications should be broad, and I think that the ones he suggests can be adopted by all

[8] McIntosh & Seymour Corp., Auburn, N. Y. Mem. A.S.M.E.

[9] Consulting Mechanical Engineer, Western Enterprise Engine Co., Los Angeles, Calif. Mem. A.S.M.E.

Diesel-engine builders: minimum gravity 24 deg. A.P.I., minimum flash of 150 deg. fahr. closed up, and maximum sulphur content of 1.5 per cent. However, I think that it is advisable to add one more specification, namely, limits for viscosity.

We all know that a very viscous oil is apt to give trouble by clogging small-size pipes, especially when the outside temperature drops sufficiently low. On the other hand, we also know that it is very difficult to keep tight glands in high-pressure fuel pumps, valves, and fuel needles if the oil is not viscous enough. Generally speaking, a gravity of not less than 24 deg. A.P.I. determines to a certain extent the viscosity, but not always in a sufficient way. Therefore it seems that viscosity limits should be prescribed but should be sufficiently broad, namely, a minimum of 40 sec. and a maximum of about 260 sec., both Saybolt Universal at 100 deg. fahr.

E. P. Kiehl,[10] and J. B. Hill.[11] The use of Diesel engines is growing quite rapidly, and the question of specifications for fuel is increasingly important. It would be advantageous if one type or grade of oil could be found suitable for all designs of engines, but this is not possible with present designs. It is desirable to restrict the number of oils to as few as possible and to make the specifications as broad as possible. We do not agree with Mr. Michler that fuel specifications should consist of minimum gravity, sulphur content, and flash, since we consider these three items the least important. The specific gravity only furnishes a rough index of the general type of the oil and a very rough estimate of the heat values. The flash point only measures the danger from fire in transporting and storing the oil. The amount of sulphur has little if any influence on the behavior of the engine.

The viscosity has a very important bearing on the ease of atomization and consequently on the thermal efficiency of the engine. Oils of low viscosity tend to produce smoother operation and a cleaner engine than oils of high viscosity. It should be noted, however, that if the viscosity is too low, trouble may be experienced in the fuel pump, which in a great many designs relies on the fuel oil for its lubrication. Heavy asphaltic matter probably has an influence on the performance, principally on coke troubles around the exhaust valve. The specification for this quality might be the A.S.T.M. precipitation number or some other equally simple test. Some of the troubles in Diesel-engine performance can be traced to foreign matter, and the quantities of inorganic ash, insoluble matter, and water should be limited by specification. We feel that a specification of the following points should insure better operation than the suggested specifications of Mr. Michler:

Max. and min. Saybolt Universal viscosity at 100 deg. fahr.
Maximum asphalt
Minimum Pensky-Martens flash deg. fahr.
Maximum ash content, per cent
Maximum sediment, per cent
Maximum water, per cent.

The case which Mr. Michler mentions in which a supposedly better grade of Diesel fuel gave trouble when the poorer grade did not, is, in our opinion, attributable to the fact that the engine was adjusted for the poorer grade and was capable of handling it, and the change to the cleaner and lighter oil without adjustment might have been expected to cause trouble.

L. K. Doelling.[12] As the Diesel engine is a very flexible engine and there are very few oils that cannot be burned successfully, I believe we should not make complicated specifications for a few exceptions. We have not found a single oil not suitable to be burned in a Diesel engine in the last five years.

About 23 years ago I drafted the first specification for fuel oil. It was short, but as time went on and we met with difficulties, we added to the specification. It should be remembered that at that time we built a low-pressure oil engine which is more sensitive. It was not long before the specifications covered a whole page, and we found considerable sales resistance because customers objected to the specifications for the oil.

About two years ago we drafted a new specification which is simple but apparently answers the purpose as we have not encountered any difficulties. It reads as follows:

> The engine will burn any commercial fuel oil produced in the United States or Mexico, and such crude oils or crude oil mixtures are now successfully being used in Diesel engines of similar size.

H. E. Brelsford.[13] The oil companies seem to think that "oil is oil," and any Diesel-engine company that will put an engine out without specifying the kind of oil to be used in it is certainly hunting trouble. Mr. Nibbs hinted somewhat, and quite specifically, at the variations in oil. I remember when I took organic chemistry in school we had a Russian professor, and our introduction to the hydrocarbon group was this: "Gentlemen, there are more than fifty-thousand compounds in this group, and we don't take all of them in this semester."

I think this whole thing simmers down to this:

No one today that I know of is building a universal atomizer, that is, one that will burn any oil that may be put in it in any engine in any part of the world. Over in Europe they are burning 33 or 34 B. fuel oil.

In this country you cannot control the kind of oil that a customer wants to use in his engine, and therefore a specification on fuel oil should be such that an engine builder can build an engine with an atomizer that will be entirely satisfactory, according to the specifications given for that engine. And then if any one wants to burn some other kind of fuel, the burden of making such changes or readjustments should not be up to the builder of that engine, but the expense should be borne by the customer. I think for that purpose a standard fuel oil is probably the desirable thing.

W. H. Butler.[14] One of the first things I should like to mention is that the statement that the oil companies are not in agreement is very true, and sadly true. If they were, the conditions we are facing today would not be as important as they are. If in the beginning the Diesel-engine industry and the oil companies had stood together and worked out their specifications together, and the Diesel-engine industry had built the engine around the specifications, then today we should not be trying to furnish numerous grades of oil for various engines.

For instance, there is one motorship running in New York harbor that if it were bunkered with an oil with a viscosity below 60, could not get out of the harbor.

There are two things I want to bring up, and one is the B.t.u. per lb. In test work, of course, everything is figured on B.t.u. per lb., but we do not burn the oil by the pound, but by the gallon, and why not specify the B.t.u. per gallon? We inject a definite amount of oil into the combustion chamber, and that is a volumetric measurement, not a weight measurement. If we look over some of the theoretical measurements of B.t.u. per gal. and per lb., we shall realize that condition. For instance, 32 gravity oil has 19,530 B.t.u. per lb., the weight is 7.169, and the B.t.u. per

[10] Power Engineer, The Atlantic Refining Co., Philadelphia, Pa. Mem. A.S.M.E.

[11] Chief Chemist, The Atlantic Refining Co., Philadelphia, Pa. Mem. A.S.M.E.

[12] De La Vergne Machine Company, New York, N. Y. Mem. A.S.M.E.

[13] Washington Pump & Machy. Co., Buffalo, N. Y.

[14] Standard Oil Co., New York, N. Y.

gal. is 140,010.57. And then we come to 20 B. oil, which has a weight of 7.772, with 19,050 B.t.u. per lb. and 148,056.00 B.t.u. per gal.

At one time our company was experimenting with some heavy oil which quite a few men present have used and tested. We showed some very peculiar results. We would take gas oil, 32 gravity, run it against this oil, which was 18 gravity, and show a 6 per cent saving in fuel. It is merely in the difference in the weight and number of B.t.u. per gallon. This was not only proved in the test which was made, but certain small boats running in New York harbor, covering a period of 18 months, showed month in and month out a 6 per cent saving, due to the weight and the number of B.t.u. per gallon.

Gravity has always been accepted as a standard specification for a Diesel fuel. Of late years this has become unimportant, for the gravity range no longer is a criterion of the function of the oil. It is our contention that viscosity should be a standard specification. In atomizing a fuel we are attempting to produce from a given quantity the greatest possible number of the smallest possible drops. As the volume decreases by the cube of the diameter and the surface decreases by the square of the diameter, then in spraying of fuel surface, tension plays a very important part. Viscosity is a fair indication of the surface tension.

If we plot the curves of various oils from the very volatile substance of the heavier oil over a wide range of temperatures, we find that the surface tension decreases with the viscosity. There has been some work done on this subject at Bayway Research Laboratory, but so far as we can find, no one has attempted previously to prove the relation between viscosity and surface tension. At one time gasoline was quoted in terms of gravity, which at present is obsolete. The same should hold for Diesel fuels, especially since cracking has become prevalent. The gravity of an uncracked stock will be 20, with a viscosity of 150 sec. Universal and a surface tension of 29.5, while a cracked stock of the same gravity will have a viscosity of 50 sec. Universal and a surface tension of 18.5. We have gone into that very carefully and have obtained a great many figures, and our laboratories are still working on it. Any further information that we obtain we shall be glad to pass on to the Diesel-engine industry.

We can give various examples of this with widely varying gravities, and yet hold the viscosity and surface tension consistently. As the Diesel-engine industry develops we shall make use of more cracked products for fuel, thereby rendering the gravity specifications even less reliable, while on the other hand, if we accept the viscosity specification no matter what the stock, we have an indication of surface tension and thereby an indication of how thoroughly the oil will atomize. This is more vital today owing to the rapid progress made in high-speed Diesel engines. The qualities limiting the speed of a Diesel engine are the ignition lag and combustion time, which are products of atomization. We are attempting by atomization to produce a homogeneous air-fuel ratio. To do this we must expose the greatest possible area to the available air, for the rapidity of combustion is proportional to surface; therefore we are not interested in the weight of a Diesel fuel, but in an indication of how rapidly the oil will atomize.

Mr. Weise, of the United States Shipping Board, asked for information on the fuel that we had been working on, and spoke of it as a bunker C oil. This was an experiment which we were working on. We put up a plant with 250 bbl. capacity, and we worked on it for two years, producing different kinds of fuel. We would take a heavy product and produce from it a very low viscosity and thereby a low surface tension. That would work very well in certain types of engines. It was tested in practically every engine made. We even sent samples to Germany, and they ran these tests in the engines of leading European manufacturers of Diesel engines. We got very satisfactory results from those tests. Today we are not going into it, because of the economic conditions in the oil companies today. At some future time, if the lighter oils become scarce and the cycle swings around, we shall go into this proposition, and practically guarantee that we can furnish an oil of 12 or 18 gravity that will meet specifications and will burn with no trouble in engines.

There has been discussion relative to the Italian tar test, which is really a lubricating-oil test, determining the sludge that can be produced in the oil. It means nothing in fuel oil. You can sludge any oil by this method, but of course lubricating oils begin to sludge at a very sticky and slimy stage, that which adheres to pipes and strainers, and it is not advisable for any fuel oil. However, this sludge is a homogeneous mixture with fuel oil and is burned readily.

Among the various complaints received, and the troubles reported by the operators of Diesel engines, we have found as a rule that the plant was as much to blame as the oil. In other words, the fuel tanks had not been cleaned, and improper methods were used in straining oils. Any oil is bound to carry a certain amount of sediment out of the tank cars, including salt water, scale, etc., and when thousands of gallons of oil are passed through the tank during a year, a certain amount of the sediment which settles, gets into the oil and is bound to cause trouble, even though that material would not show up in the analysis. Consequently, if the fuel tanks are not cleaned consistently and persistently, the operators are going to experience trouble due to that fact.

Limiting specifications will not eliminate troubles. There are lots of things about oil that we do not and will not know for a number of years. A certain company had a very peculiar complaint from one of their users several months ago, and got in touch with the writer's company. The oil was not supplied by them, but by another oil company in another locality. Looking into the matter, it was found that the specifications were beyond reproach. It was found at that time that the particular batch of oil that had been delivered and used in that engine had a high percentage of aromatics. It would not show on the specification, and there was no way in the world to determine it except by test. The various types of materials and compounds in their relation to the oils are so complicated that one batch of oil from one refinery, treated under certain conditions, will be entirely different from that from another refinery. The same is true with the by-products.

Those things are out of our control, and out of the control of every one else, but if we can get a set of specifications that are agreeable to every one, and yet fair to every one, it will solve our problem, and also advance the development of Diesel engines considerably.

Oliver F. Allen.[15] I wish to speak about the comparative cost of oil used in steam apparatus and in internal-combustion engines. It has been stated here that the ratio is 1 to 3; that is, steam equipment requires three times as much fuel as that used by the internal-combustion engine, doing the same class of work. I think that is true in the average marine and land equipment today. But we are looking to the future. Consequently we should use as a measuring stick the best performance at the present time, and that best performance represents a ratio of 2 to 1 and not 3 to 1.

I believe that when certain marine steam installations which are now under construction and being studied are put into operation, it will be found that they have practically caught up with the Diesel in some classes of service. So the question of utilizing the same grade of oil in internal-combustion engines

[15] Manager, Automotive Sales, International General Electric Co., Schenectady, N. Y. Mem. A.S.M.E.

that is used under boilers is of prime importance. For the steam plant is going to give the Diesel a race in the matter of overall efficiency.

Another point is that the performance of the small engine and the high-speed engine must not be confused with that of the larger type, such as the central-station engine and the marine engine. In every one's home there is a heating unit, a little steam or hot-water plant, and if manufactured gas is too expensive, coal is used, not dirty soft coal but the cheapest acceptable fuel obtainable. It is the same with a big power plant; the owner obtains the cheapest fuel that he can get. The Diesel station must get oil where it can get it at a reasonable price.

I had occasion recently to inquire into what is being done by the preeminent users, and found that the marine people are almost universally centrifuging, even if they get what they consider clean oil; and particularly is that true among the British owners. It also seems to be the tendency to improve the quality of the filters. For instance, Hesselman-A.E.G. are making their filters with passages finer than any opening they have in any part of the fuel-oil system, that is, the opening of any fuel valve or nozzle. I think most of the foreign manufacturers are emphasizing the importance of having clean, free-flowing fuel-oil lines, and they are not only heating the oil as it goes through the pipes into the pumps, but are heating it right up to the point of injection so as to insure adequate control of the injection itself.

Lloyd Yost.[16] The comments made by Mr. Nibbs, seem to be probably the nearest to the solution, from the engine-builders' standpoint. There are certain things in a fuel oil that must be considered from other than the purely petroleum-technology standpoint. In selling engines we must place our bids according to the specifications offered (and by bids I mean that guarantees of performance must accompany the bids) and if the engine does not perform, then the builder must make good, if he is capable of making good. That means the oil specified should be a commercial product, something that a customer can obtain—and he must not be misled. Guarantees of fuel consumption are made, of course, in terms of weight. A specification in terms of so many B.t.u. per gallon would be acceptable if one could get the purchaser of the engine to understand and accept it. I do not see that this makes very much difference to him, but it is an important point when guaranteeing the fuel consumption of your engine.

We have found out the only way to determine how a fuel oil will perform in a Diesel engine is to try it in one. At the same time we make a scientific laboratory examination, including fractional distillation. Up to this time we have distilled and tested over 1500 commercial grades of fuel oil. We have tabulated those results, and after going through them backward and forward, so far we have been unable to determine a specification that would be fair to ordinary engine buyer and also fair to the builder of the Diesel engine. In that case we must fall back upon the commercial factor, pure and simple, and refer to the oil as put out under a certain brand, and then write into the specification that this engine will perform under such guarantees "when using any brand listed on the attached sheet," which lists a great many of them, several hundred perhaps, or "oil equal to any one of those listed." That is as close as we have been able to come to it. We think this thing of an oil specification is very important, and we wish we had one, but it is necessary, as we see it, for all of the engine builders to agree—I don't know if it can be done—upon a certain specification. In testing these oils, we have found that you cannot put all fuel oils into any one classification or include them with the others and still be fair to the user. We have adopted a triple classification: (1) an oil which is satisfactory for use directly in the engine, using the standard equipment; (2) an oil which may be such as to require preheating or treatment in order that it may be used satisfactorily; and (3) an oil which may have a low heat content or other characteristics which will not allow it to make the required fuel consumption. Naturally there are some oils that are not usable in any circumstances, but those would not appear on the list at all.

[16] Manager, Research Division, Fairbanks, Morse & Co., Chicago, Ill. Mem. A.S.M.E.

J. C. Groff.[17] Mr. Michler's paper is appropriately in line with the trend of modern industry toward the elimination of overlapping of products. Further lowering of the cost of fuel oils for Diesel engines should be achieved through broadening of needlessly restrictive specifications. It is not difficult to imagine what the price of automobile fuel would be today or to what extent the enormous growth of the automotive industries would have suffered had these respective engine builders demanded rigid adherence of their products to superfine grades of fuel. Similarly, it would seem that extensive adoption of the Diesel engine, particularly in this country where it must compete with the steam plant having available a plentiful supply of low-priced boiler fuels, will be largely dependent upon its ability to operate satisfactorily upon widely varying grades of fuel oils. Only in this way can the Diesel engine take advantage of the most economical grades of fuel, and only in this way can the shipowner be assured that his vessel will be able to operate to advantage in all parts of the world.

The three limiting specifications, as suggested by Mr. Michler, in conjunction with minimum content of ash, carbon residue, sediment, and water, should be generally satisfactory. The following section is from the standard guarantee contract specifications adopted for our oil engines: "Fuel oil, before being delivered to the engine, to be passed through a centrifuge of approved type. Centrifuge to be furnished by purchaser. We suggest fuel oil of 18 deg. to 22 deg. B. gravity. Sulphur content may be any amount not exceeding $3^1/_2$ per cent."

It is presumed that the minimum gravity of 24 deg. A.P.I. has been so chosen in conjunction with an initial viscosity which will assure fluidity at low temperatures, say, 32 deg. fahr. Many motorships, particularly those carrying fuel in double-bottom tanks and not fitted with heating coils, experience difficulty in handling fuels having a high viscosity at low temperatures. Indeed, our experience has shown that handling the fuel up to the engine is much more of a problem than burning it. Proper prehandling of fuel oils by the user would seem to offer one of the most likely means of assisting all concerned in the broadening of specifications for the cheapening of fuel.

C. E. Cox.[18] I am heartily in accord with Mr. Michler's recommendation that a set of standard specifications for Diesel fuel oil be prepared and adopted, but also believe that the interests of Diesel-engine builders should be protected as well as those of the fuel-oil refiners and dealers. Broadening the specifications as far as he suggests will undoubtedly favor the refiner but will not sufficiently protect the engine builder, because there are certain properties and constituents of fuel oil not limited in his recommended specifications which may render a fuel oil unfit for Diesel-engine use, owing to the fact that they are positively injurious to the engine. While it is true that refiners and dealers in oil cannot carry a large variety of oils meeting various specifications, yet it seems to us entirely possible for them to carry a grade of oil which will successfully meet the majority of specifications presented by engine builders.

[17] Engineer, Power Division, Bethlehem Steel Co., Bethlehem, Pa. Mem. A.S.M.E.

[18] Chicago Pneumatic Tool Co., Franklin, Pa.

Almost all engine-builders' specifications for fuel are of the limiting type; that is, they do not attempt to define any limits farther than those tending in a detrimental direction. Experience has proved that certain properties of any ingredients in fuel oils if existent in excess of certain quantities produce unfavorable operating conditions. It is therefore necessary that the engine builder limit these unfavorable factors to safe values in order to be able to make his guarantees and to protect the engine owner. Fuel specifications are thus made to look very rigid, while as a matter of fact the majority of fuel oils will meet them easily. Once the dealers' and refiners' attention is directed toward these points, the ready adoption of a standard fuel will rapidly develop and the name "standard Diesel fuel oil" can be applied.

The specifications, while appearing to cover minutely every property and constituent of the oil, in fact are so liberal that few if any oils that would ever be submitted by a refiner or dealer will fail to meet them. Many products are marketed today under strict, lengthy specifications that have been complied with so long and so easily that they are seldom referred to. Portland cement might be cited as an example. There is no reason why such cannot be the case with Diesel fuel oil. On this basis, then, I believe that the specifications should be complete and yet broad enough in their limits to avoid expensive processes in producing the fuel oil. An oil dealer should know even without analysis that his oil will meet these specifications, and the engine builder will know what the worst operating conditions are that he must meet. Any hardships that may result will more likely reflect on the engine builder than on the refiner or dealer. It is assumed that the fuel oils under discussion are petroleum, and it is on this basis that we proceed.

The following properties are known to affect the operation of a Diesel engine and are the ones which we believe should be considered in defining a standard Diesel fuel oil:

1 Gravity
2 Viscosity
3 Sulphur
4 Ash content
5 Coke content
6 Water content
7 Heating value
8 Flash point.

Gravity has no influence except to supply a conversion factor for converting barrels to pounds. So far we can learn, it gives no index as to the probable properties of the oil unless the origin is known. Gravity in our opinion could be limited to a value of 24 A.P.I. very readily.

Viscosity is important, for the oil must flow readily enough under normal winter temperatures to be handled by injection pumps and nozzles; beyond that its influence is slight. Viscosity should be limited to a value of 200 at 32 deg. fahr. Giving the viscosity at 100 deg. fahr. its worse than useless, for that gives no indication of what it may be at the operating range for oils in general.

Sulphur tests have shown that a high sulphur content is not severely injurious. Limiting it to Mr. Michler's content of 1.5 per cent is therefore very liberal, and it might be raised to 2 per cent.

Ash content is important and extremely so, as the ash affects lubrication seriously, causing worn parts, sticking rings, and rapid wear. Ash should by all means be included, and should be limited to a value of not more than 0.05 per cent. It is hoped that some experienced refiner will announce that no fuel oils ever contain ash nowadays. If such is the case, then the specifications will not burden the oil refiner and yet will protect the engine builder.

Coke or carbon residue is important. Some California and Mexican oils have a very high content, the oils appearing to crack and form coke, which spoils lubrication and fouls the engine rapidly. Wear takes place and reliability is badly affected. The coke content should therefore be included and limited to 3 per cent, a value easily attainable by refiners of petroleum oils.

Water mechanically entrained will cause failure of ignition and unsteady operation of the engine. Water mixed with the oil in the form of an emulsion does not necessarily interfere with ignition, but higher temperatures are required to ignite and burn such oils. Water lowers the heating value of the fuel. A purchaser of oil should not pay for water and the cost of transporting it. Its value should be limited to 1 per cent.

The heating value of fuel oils is not so important, I believe, owing to the fact that nearly all oils run 18,000 B.t.u. or higher. When a builder is making a fuel guarantee a variation of 1000 B.t.u. is a considerable amount, and he therefore has to limit his fuel to a definite value. It would be advantageous to make all guarantees on a basis of 18,500 B.t.u. minimum, making no correction for fuels having values higher than this. This would favor the refiner as well as the engine builder.

Flash point is purely a storage problem and affects the engine operation very little. This item must be considered because of other influences. Mr. Michler's value of 150 deg. should be easily acceptable.

To summarize, we believe that such standardized fuel should be well defined as to detrimental factors, but so broadly limited as to not impose any hardships on the refiner or to cause a reflection of too strict specifications in an increased price for the fuel. The engine builder will then know what range of fuels his engine will be called upon to operate on, and can govern the design accordingly; the engine owner will be spared the trouble of buying fuel to rigid specifications, and whenever fuels are offered that do not come within the limits of the specifications, the purchaser should benefit by a differential in price. Engine builders, will be protected against having to make blind guarantees, and will have a general standard that they should be able to live up to. The mere adoption of these specifications does not imply that every batch of oil must be tested—far from it! It should not be necessary. If the refiner has kept proper check of his process, he should know that his oil is well within these specifications. There is no reason why the Diesel engine should become a disposal plant for all manner of refinery and oil-production wastes, and engine builders should not have imposed upon them all the burden of the fuel problem.

OGP-50-11

# The Economic Field for Large Diesel Engines

By EDWARD B. POLLISTER,[1] ST. LOUIS, MO.

*The author defines a large Diesel engine as one ranging from 2500 to 25,000 hp. He cites the successful performance of marine Diesels, and gives figures showing that the aggregate horsepower of such engines now being built or installed is over three times that of marine steam turbines. He points out territory far removed from coal mines and where a cheap supply of fuel oil makes the use of the Diesel engine especially desirable. Over half of the fuel oil consumed in generating electric power, he states, could be saved by burning it in Diesels rather than under boilers. Diesel generating stations cost about the same as modern steam plants, around $135 per kw. Diesels have characteristics which especially fit them for use as auxiliaries in steam and hydroelectric power plants. The paper concludes with a brief consideration of the use of large Diesel engines in industrial plants.*

EARLY in the year 1924, an engineer waiting in a railroad station in the Panama Canal Zone idly turned the pages of a *Saturday Evening Post* and saw the advertisement of an American firm claiming for the Diesel engine "instant readiness

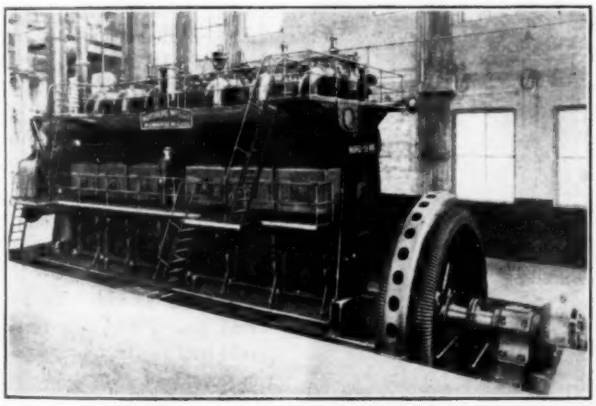


FIG. 1 3750-HP. PANAMA DIESEL BUILT BY NORDBERG MANUFACTURING CO., MILWAUKEE, WISCONSIN

for service." If true, the Diesel was just the prime mover he wanted for the proposed new 12,000-hp. Canal power station at Miraflores, to supply power in case of failure for any cause of the power transmitted from the Gatun hydroelectric station, about 36 miles distant, over a 44,000-volt transmission line.

He immediately started a serious investigation of the large Diesel. A natural beginning was the inspection of Diesel-propelled ships passing through the Canal. Quick starting and performance being convincingly established by records of ships propelled by single-screw Diesels of several thousand horsepower in round-the-world service, the safety of ships and crews depending on one engine, with non-stop runs as long as forty-five days, he set out on a visit to the Diesel firms of the United States where he was enthusiastically received.

Special automatic equipment was worked out between the Diesel-engine builders and the generator manufacturers which would permit motoring of the idle engines by the generators operating as synchronous condensers for power-factor improvement and voltage regulation, any transmission line or similar power failure automatically causing a transition from idling condition to load condition and thus providing for continuing the important power service to the Canal uninterrupted. This quite fully satisfied the claim for "instant readiness for service."

Although the desired unit size, 3750 b.hp., was larger than any Diesel which had at that time been built in the United States, it is astonishing that no less than eight substantial American heavy-machinery firms considered the large Diesel engine field sufficiently attractive to justify bidding on, an undertaking which for many involved a development expense of several hundred thousand dollars. A list of these firms follows, and all of them now have marine Diesel engines of 2500 b.hp. or larger in service.

Bethlehem Steel Corporation
Busch-Sulzer Bros.-Diesel Engine Co.
McIntosh & Seymour Corporation
New London Ship & Engine Co.
Nordberg Manufacturing Company
Sun Shipbuilding Company
Wm. Cramp & Sons Ship & Engine Co.
Worthington Pump & Machinery Corporation.

The building of the Miraflores Diesel plant was carried through to successful conclusion, three Nordberg 3750-hp. engines being supplied. This project would indicate a favorable outlook for large Diesel engines for standby service entirely aside from the

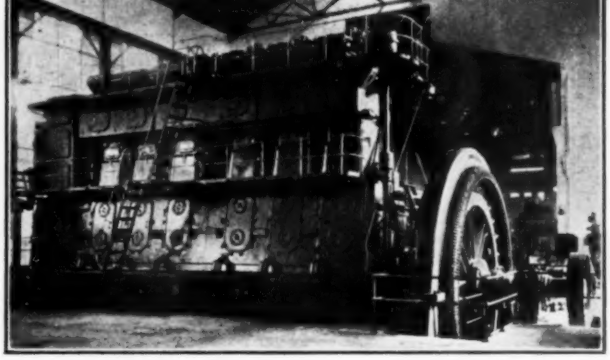


FIG. 2 3750-B.HP. BUSCH-SULZER DIESEL GENERATING UNIT, FEDERAL LIGHT & TRACTION CO., TUCSON, ARIZONA

more prominent advantage of the Diesel—its high thermal efficiency of about 33 per cent—which has not yet been approached by any other type of prime mover. But in the intervening four years only one Diesel of this size, a Busch-Sulzer 3750-hp. unit, selected by Sanderson & Porter for the Tucson, Arizona, plant of the Federal Light & Traction Company, has been purchased in this country for stationary service, and no larger units for land plants.

### WHAT IS A "LARGE" DIESEL ENGINE?

A proper question may be, "What is a *large* Diesel engine?" Diesels built by Sulzer Brothers, of Winterthur, Switzerland, of 4000 hp. capacity have been operating in European land stations for over fifteen years. In the same year that the Panama Canal invited bids on 3750-hp. Diesel engines, the Hamburg Electric Company, of Hamburg, Germany, placed an order for a 15,000-hp. two-cycle double-acting M.A.N. Diesel generating unit for in-

[1] General Manager, Busch-Sulzer Bros.-Diesel Engine Co.

Presented at the First National Meeting of the A.S.M.E. Oil and Power Division, the Pennsylvania State College cooperating, State College, Pa., June 14 to 16, 1928.

stallation in their electric generating station to carry peak loads. While this is the largest Diesel now in operation, Sulzer Brothers have developed a single-cylinder experimental double-acting two-cycle engine rated for stationary work at 2400 b.hp. at 110 r.p.m. with a cylinder bore of 900 mm. and a piston stroke of 1400 mm. A 10-cylinder engine of this size would develop 25,000 b.hp. This number of cylinders is frequently employed in marine work, and Sulzer Brothers have supplied eight 10-cylinder units averaging above 5000 hp. each for propelling ships. As 900 mm. diameter of cylinder is not the limiting size, a former Sulzer single-cylinder experimental engine having a bore of 1000 mm., somewhat larger units are not without the range of conservatism. A large Diesel may therefore be considered as of from 2500 to 25,000 b.hp.

### Marine Diesels

In considering the economic field for large Diesel engines in this country, it is important to note that the successful performance of large marine Diesels was a vital feature in the decision to go ahead with the 12,000-hp. Panama Canal power plant; and the extremely rapid adoption of the Diesel for the propulsion of ships has eliminated what might be the fear of experimental development by possible purchasers of large land Diesels. The largest motorship in service, the *Augustus*, of 32,500 gross tons, is propelled by Diesels totaling 28,000 hp. The proposed reconditioning of the Shipping Board steamer *Mount Vernon* calls for two propelling Diesels of 14,500 b.hp. each, and a total Diesel plant of 35,000 to 40,000 b.hp. These large engines can be furnished in the same American-built cylinder sizes as are now successfully operating in round-the-world marine service. The survey herewith, as of December 31, 1927, of marine engines under construction throughout the world discloses that the aggregate horsepower of Diesel engines building or being installed is over three times that of steam turbines (excluding Germany—figures not available), and that the tonnage of motorships now building is greater than that of steamships.

| | Steam Engines | | | | Oil Engines | |
|---|---|---|---|---|---|---|
| | Reciprocating | | Turbine | | | |
| | No. | I.hp. | No. | I.hp. | No. | I.hp. |
| | 327 | 556,874 | 34 | 343,700 | 352 | 1,233,956 |
| Average size | | 1700 | | 10,000 | | 3,500 |

Total gross tonnage under construction { Steam....... 1,494,532; Diesel....... 1,609,888

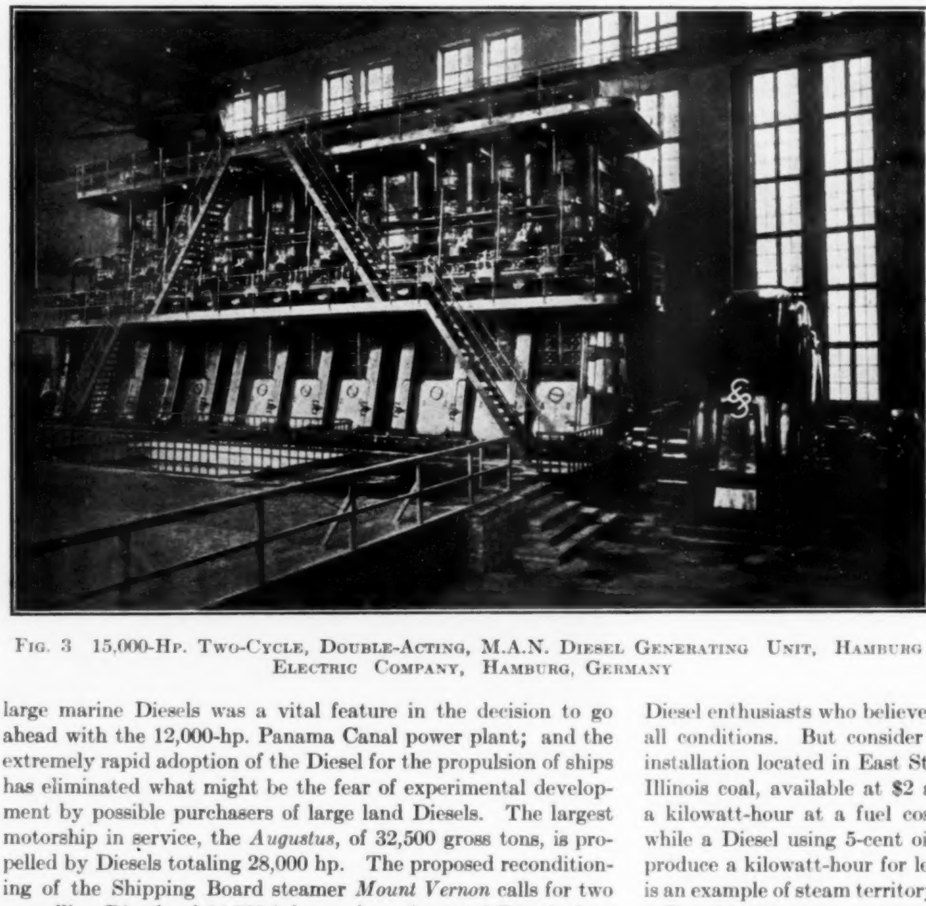


Fig. 3 15,000-Hp. Two-Cycle, Double-Acting, M.A.N. Diesel Generating Unit, Hamburg Electric Company, Hamburg, Germany

The trend toward Diesels is indicated by a statement issued in April of this year by Lloyd's Register of Shipping for the first quarter of 1928, showing a gain to March 31, 1928, of oil engines to 1,333,875 i.hp. compared with a decline of steam turbines (excluding Germany) to 277,600 i.hp., and a decline of steam reciprocating engines to 549,910 i.hp. This ratio of five to one for marine Diesels as compared with steam turbines demands the serious attention of designers of land power plants.

But, with this brief mention of marine Diesels, it is necessary, in view of the limitations of the present paper, to return to land plants, and without much encouragement from existing installations in this country, outline the future of the large stationary Diesel.

### Territory Especially Adapted to Use of Diesel Engines

As a general statement, the United States is a country of cheap coal; and as the greatest industrial developments originally centered around the coal mines of the East, the great power-plant engineering problems have been worked out without any consideration of the Diesel whatsoever. Obviously, steam plants of half the thermal efficiency of the Diesel, using local cheap coal, can produce power at less fuel costs than Diesels requiring liquid fuel if the cost of the liquid fuel at the oil field plus the cost of transportation (which is often several times the cost of oil at the point of production) is sufficiently in excess of twice the cost of local coal on a B.t.u. basis. Of course we shall always have with us Diesel enthusiasts who believe that Diesels can beat steam under all conditions. But consider a large up-to-date steam-turbine installation located in East St. Louis, and burning 12,500-B.t.u. Illinois coal, available at $2 a ton. Such a plant will produce a kilowatt-hour at a fuel cost of between one and two mills; while a Diesel using 5-cent oil brought from Oklahoma, cannot produce a kilowatt-hour for less than twice this fuel cost. This is an example of steam territory.

But this is a country of vast area, and there are large sections, especially through the Middle West and along the seaboard, remote from coal mines, and within easy reach of oil fields or a cheap supply of fuel oil transported at low costs in ocean-going tank ships. These are decidedly examples of Diesel territory.

Also, industry is moving westward with the center of population, and the demand for power throughout the great West is growing with the increase of population. This is favoring the more general adoption of the large Diesel.

The tabulation herewith of the consumption of fuel oil in generating electric power by public-utility power plants in 1927

| Division and State | Barrels | Per cent of U. S. total |
|---|---|---|
| United States | 6,782,199 | 100.00 |
| New England | 858,289 | 12.65 |
| Middle Atlantic | 342,462 | 5.05 |
| East North Central | 68,456 | 1.01 |
| West North Central | 815,534 | 12.02 |
| South Atlantic | 2,048,991 | 30.21 |
| East South Central | 57,977 | 0.86 |
| West South Central | 929,581 | 13.71 |
| Mountain | 225,889 | 3.33 |
| Pacific | 1,435,020 | 21.16 |
| New England: | | |
| Maine | 30,842 | 0.46 |
| New Hampshire | 1,555 | 0.02 |
| Vermont | 30,221 | 0.45 |
| Massachusetts | 628,072 | 9.26 |
| Rhode Island | 167,225 | 2.47 |
| Connecticut | 374 | 0.01 |
| Middle Atlantic: | | |
| New York | 323,983 | 4.78 |
| New Jersey | 9,615 | 0.14 |
| Pennsylvania | 8,864 | 0.13 |
| East North Central: | | |
| Ohio | 8,846 | 0.13 |
| Indiana | 9,486 | 0.14 |
| Illinois | 27,101 | 0.40 |
| Michigan | 13,821 | 0.20 |
| Wisconsin | 9,202 | 0.14 |
| West North Central: | | |
| Minnesota | 6,911 | 0.10 |
| Iowa | 41,694 | 0.62 |
| Missouri | 103,818 | 1.53 |
| North Dakota | 1,855 | 0.03 |
| South Dakota | 37,845 | 0.56 |
| Nebraska | 84,708 | 1.25 |
| Kansas | 538,703 | 7.94 |
| South Atlantic: | | |
| Delaware | 0 | 0.00 |
| Maryland | 3,182 | 0.05 |
| District of Columbia | 0 | 0.00 |
| Virginia | 7,884 | 0.12 |
| West Virginia | 246 | 0.00 |
| North Carolina | 2,189 | 0.03 |
| South Carolina | 4,925 | 0.07 |
| Georgia | 96,359 | 1.42 |
| Florida | 1,934,206 | 28.52 |
| East South Central: | | |
| Kentucky | 3,277 | 0.05 |
| Tennessee | 11,338 | 0.17 |
| Alabama | 12,426 | 0.18 |
| Mississippi | 30,936 | 0.46 |
| West South Central: | | |
| Arkansas | 63,605 | 0.94 |
| Louisiana | 133,665 | 1.97 |
| Oklahoma | 135,627 | 2.00 |
| Texas | 596,684 | 8.80 |
| Mountain: | | |
| Montana | 2,160 | 0.03 |
| Idaho | 0 | 0.00 |
| Wyoming | 13,603 | 0.20 |
| Colorado | 2,040 | 0.03 |
| New Mexico | 63,446 | 0.94 |
| Arizona | 104,425 | 2.07 |
| Utah | 45 | 0.00 |
| Nevada | 4,170 | 0.06 |
| Pacific: | | |
| Washington | 173,656 | 2.56 |
| Oregon | 15,857 | 0.23 |
| California | 1,245,507 | 18.36 |

shows this natural distribution of territory where oil is the logical fuel and the Diesel is the logical prime mover.

At least one-half of the greater part of these 6,782,199 bbl. of fuel oil could be saved if it were burned in Diesel engines instead of under boilers. This would be a saving of easily over $5,000,000 in public-utility fuel costs.

The comparative thermal efficiencies of Diesel-engine generating units and large steam-turbine plants are too well known to justify repeated technical discussion. There are large plants on the Atlantic seaboard (for instance, the Narragansett Power Station) where fuel oil transported in tankers is burned under boilers. The average fuel consumption per kilowatt-hour in such large modern steam plants is about 1.2 lb. of fuel oil as compared with about 0.6 lb. burned in large Diesel engines. Varying load conditions and types of equipment may, for particular installations, change slightly these figures; but they are approximately correct.

The next question to consider is whether this saving of $5,000,000 would be dissipated by fixed charges on higher Diesel plant costs or higher Diesel operating costs. While steam-plant costs are very generally known, this information is not obtainable on large Diesel-engine plants, due to lack of such installations. With so many concerns offering large Diesels in advance of actual building, prices quoted are very unstable, the market not having become established. Again, the ultimate price of large Diesel engines will only be determined after sufficient orders have been placed to produce these engines on other than single-engine orders with comparatively high cost of manufacturing.

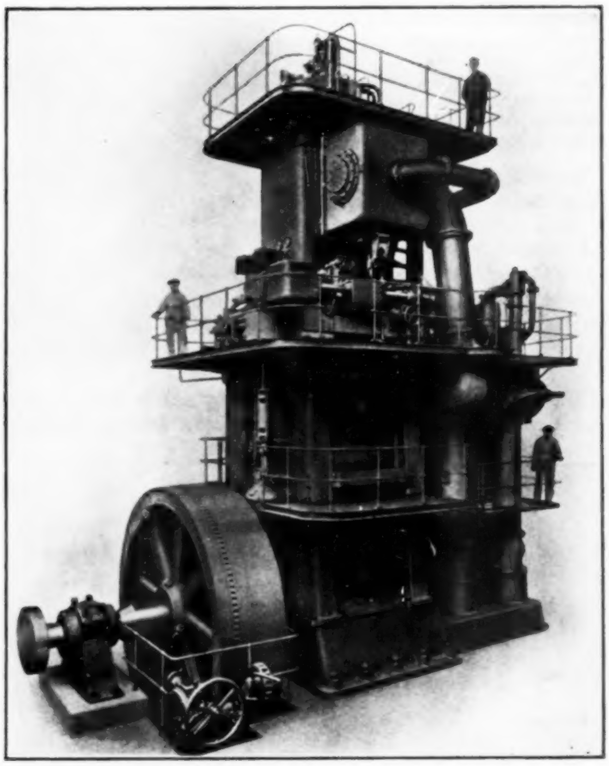


Fig. 4 Double-Acting Two-Cycle Experimental Engine
(2400 b.hp. at 110 r.p.m.; 900 mm. bore, 1400 mm. stroke; mechanical efficiency, 70 per cent.)

### Cost of Large Diesel-Engine Generating Stations

Contrary to general opinion, however, based on actual selling prices of the few large Diesels which have been sold in this country, the cost of large Diesel-engine generating stations is approximately that of modern steam plants. In fact, in many cases

the cost of the Diesel plant is less, depending upon the varying costs of providing condensing water for the steam plant. Formerly Diesel engines were comparatively high in price, but today Diesels rank with the very few commodities that are being sold for less than prewar prices. Large stationary Diesels cost less than $60 per hp. and the total cost of a large Diesel generating station is normally around $135 per kw., made up about as follows for average conditions:

Estimate of Cost of a Four-Unit, 15,000-B.Hp. 10,000-Kw. Diesel Installation

| | |
|---|---|
| Real estate | $ 10,000 |
| Building, including 20-ton crane | 75,000 |
| Foundations | 40,000 |
| Four 3750-b.hp. Diesel engines, f.o.b. point of manufacture | 900,000 |
| Freight on engines at $1 per cwt | 40,000 |
| Generators and exciters, direct-driven | 100,000 |
| Freight on generators and exciters | 5,000 |
| Unloading and placing on foundations | 15,000 |
| Erection | 15,000 |
| Station piping | 15,000 |
| Cooling-water system (if required) | 25,000 |
| Fuel storage | 10,000 |
| Switchboard and wiring | 20,000 |
| Miscellaneous items, contingencies, and engineering | 80,000 |
| Total | $1,350,000 |
| Diesel station cost per kilowatt of installed capacity | $135 |

It should be noted that the installation is extremely simple, approximately only one-half of the floor space being required that is necessary for turbine installations, the building being somewhat lower, and expensive smokestack, coal and ash-hauling apparatus being absent. Fig. 8 showing the comparative floor space of a 20,000-b.hp. electric station with four units of 5000 b.hp., steam turbines—Diesel engines, is taken from a catalog of Sulzer Brothers, Swiss builders of Diesels as well as

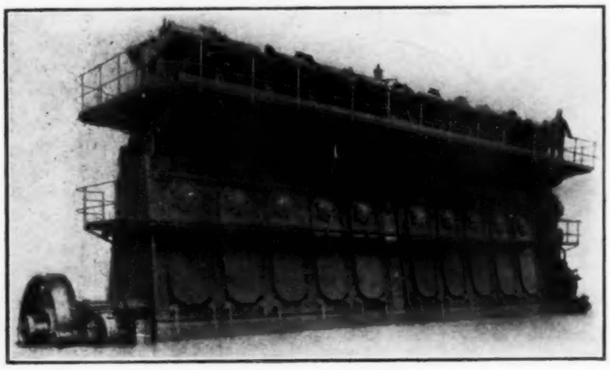


Fig. 5 Sulzer Bros. Marine Type 10-Cylinder Two-Cycle Engine, 5800–6800 Hp.

of steam turbines and boilers. The simplicity and small size of the building is quite well established by Fig. 9, which shows a 20,000-hp. 6-unit Sulzer Diesel plant installed at Shanghai, China.

As the size of the Diesel increases, the maintenance cost diminishes. The replacing of a working part on a 36-in.-diameter cylinder rated at 2000 hp. does not cost ten times as much as a similar part on an 18-in. cylinder rated at 200 hp. This is apparent and will become established in this country after more of these large Diesels have been installed.

Similarly, the same operator who takes care of a 500-hp. Diesel engine can as well take care of a single engine several times as large. There is no more to do while the engine is in operation. Adjustments and upkeep work would be somewhat greater of course, but not in proportion to the increased size of the larger engine.

And so this fuel saving would be a net saving and added to the net income of public utilities.

Here, then, is the first economic place for the large Diesel engine, in sections of the country where the price of Diesel fuel on a B.t.u. basis compares favorably with the price of steam fuel.

## Use of Diesels in Auxiliaries in Large Steam Power Plants

The task remains, however, of convincing "dyed in the wool" steam engineers, who will, of course, still insist on having steam

Fig. 6 McIntosh & Seymour 2700-B.Hp. Double-Acting, Four-Cycle Marine Diesel

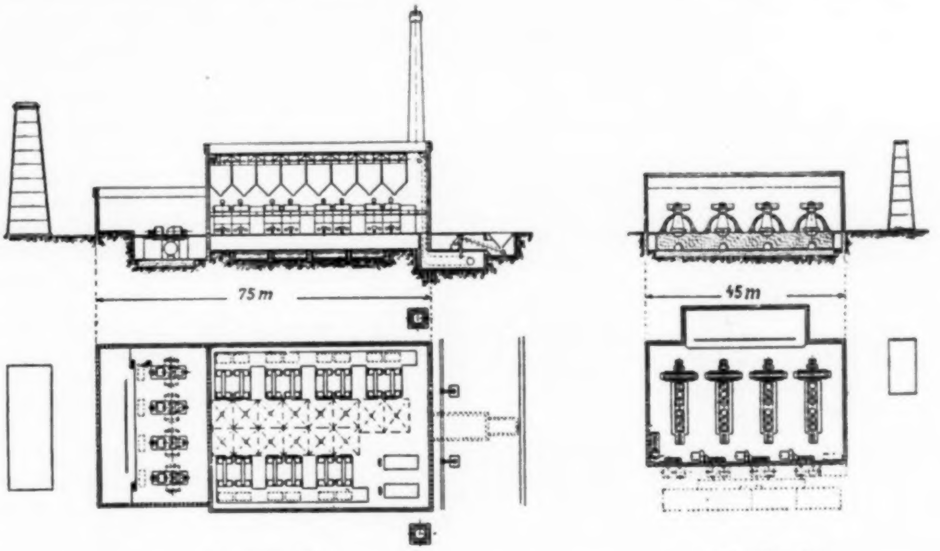
at any cost. Before reaching a decision to purchase the 3750-hp. Diesel for installation at Tucson, clearly a Diesel territory, one of these "steam" engineers organized an exploring party to see if a coal stratum could not be discovered in that locality. The geographical division of the country into cheap-coal and cheap-oil territory is a logical step in the first consideration of the large Diesel. But this is only the first step, and possibly a more important use of the Diesel is as an auxiliary to even the largest power plants, both steam and hydroelectric, because of characteristics it possesses which are too frequently overlooked. In fact, due to its limitations in size the Diesel will never be a competitor of the largest steam turbines; but it can be very advantageously used as auxiliary capacity, as follows:

1 By carrying normal peaks, permitting steam equipment to be operated at most favorable constant loads with highest efficiency
2 For emergency peaks
3 As standby and reserve to high-lines
4 Hydroelectric auxiliary.

Self-contained, with a minimum of piping and auxiliary equipment, and using easily handled and stored fuel, capable of delivering full output within a few minutes' time, simple to start up, the large Diesel generating unit, costing no more per kilowatt of installation than the overall steam plant, forms a very desirable 10 or 20 per cent of the capacity of quite large steam-turbine generating stations. The daily peak load is the bugbear of the central-station efficiency operator. It is usually of short

FIG. 7 M.A.N. TYPE, TWO-CYCLE, DOUBLE-ACTING DIESEL ENGINE, 3900 B.HP., BUILT BY THE HOOVEN, OWENS, RENTSCHLER COMPANY, HAMILTON, OHIO

duration, two or three hours only, but must be provided for either by firing up additional boilers and warming up additional turbine capacity, or operating the remainder of the day at less than the maximum efficiency loading of both. Once adopted as part-station capacity for carrying peak loads, the large Diesel will quickly become a favorite apparatus with the chief engineer and the efficiency engineer of the large power plant, as well as with the owner.




Steam Turbines | Diesel Engines

FIG. 8 COMPARATIVE FLOOR SPACE OF TWO 20,000-B.HP. ELECTRIC STATIONS WITH FOUR UNITS OF 5000 B.HP. EACH

Aside from the normal daily peak loads, there are occasional unexpected fluctuations in the load curve, especially in large cities—for instance, such as is caused by a bright day becoming cloudy. When such a sky becomes suddenly overcast with black clouds a large lighting demand, seldom felt during daylight hours, comes on quickly. For such loads, and for emergency partial breakdown of steam-power-plant apparatus, the separate, self-contained Diesel capacity serves an excellent purpose.

Eastern superpower systems are closely tied in with comparatively short distances between large generating stations. This is not the case in the West, where high-tension lines become longer and supply smaller and more widely separated communities. Further, the western part of the country is more subject to wind and sleet storms, causing damage to high-tension distribution lines which often requires many days for repairs. The pride of even small communities is humbled by a sudden return to dark nights, kerosene lamps, and candles. The support of these small municipalities as customers is almost a necessity for the proper electrical development of the western part of our country, where industrial power demands are smaller than in the East and grow at a lesser rate. Eastern holding companies who have extended their operations to the Middle West are finding out that it is extremely difficult to appease the clamorings of disgruntled small-town citizens over interruptions of high-line service. The answer is to install part of the capacity of the system in Diesel generating units placed at important feeder points and used either for constant operation, where the cost of Diesel fuel favors, with the surplus capacity in readiness in the distant steam-turbine stations for emergencies; or, where the cost of steam generation is lower, to have the distant Diesel to supply service during high-line and other interruptions, and assist in carrying peak loads.

This plan of installing Diesels is being rapidly adopted in several sections throughout the West, especially where small Diesel generating stations have been taken over by expanding holding companies, and their low-cost-production records forcibly brought to the attention of the new owners.

This system of installing Diesels at outlying points on high lines has other advantages. When a high line becomes over-

loaded, it saves increasing its capacity. Where new properties are acquired far from existing high lines and with loads not immediately justifying high-line extension, Diesel generating plants may be installed for the period of years required for the load to be built up to a point where extension of the distribution system may be profitably made. As such Diesel generating stations will produce power at costs comparable with the largest steam-turbine plants, even where steam fuel is obtainable at a more favorable cost, the rates of the large parent station may be maintained for the customers of the Diesel generating station, assisting in developing this load.

In these days of rapid improvement of steam equipment, the replacement of low-pressure boilers, turbines, and equipment which have been superseded by more efficient types, may be oftentimes deferred by installing additional capacity in more economical Diesel generating units, in many cases the partially obsolete steam equipment ultimately becoming reserve capacity.

## Diesels as Auxiliaries in Hydroelectric Plants

Another distinct field for the Diesel is as a hydroelectric auxiliary plant. During times of low water flow the Diesel may be operated with minimum attendance; depreciation is practically absent when shut down, in contrast to the heavy depreciation of idle steam equipment; the fuel is safely stored for long periods without danger of spontaneous combustion or depreciation from weathering; and the plant is compact and lends itself readily to installation in the hydroelectric turbine power house, to which the fuel is delivered by gravity pipe line. A single attendant can start even quite a large engine to carry occasional peak loads; and for more sustained seasonal operating, additional personnel can be supplied as required. The life of a Diesel operating as standby auxiliary is almost indefinite, the working parts being bathed in oil and not subject to rusting or deterioration.

Where water storage capacity is sufficient, and peak loads exceed the capacity of a hydroelectric plant, the Diesel auxiliary may be operated as a hydraulic accumulator, pumping the water back over the dam to storage during light-load periods of the day, as well as adding its capacity to the hydraulic turbines during peak loads.

Extensive study of the advantages of large Diesel-hydroelectric auxiliary plants has been made during the past ten years, and each time the lack of actual installations of large Diesels has introduced an experimental hazard which for so large an investment has prevented con-

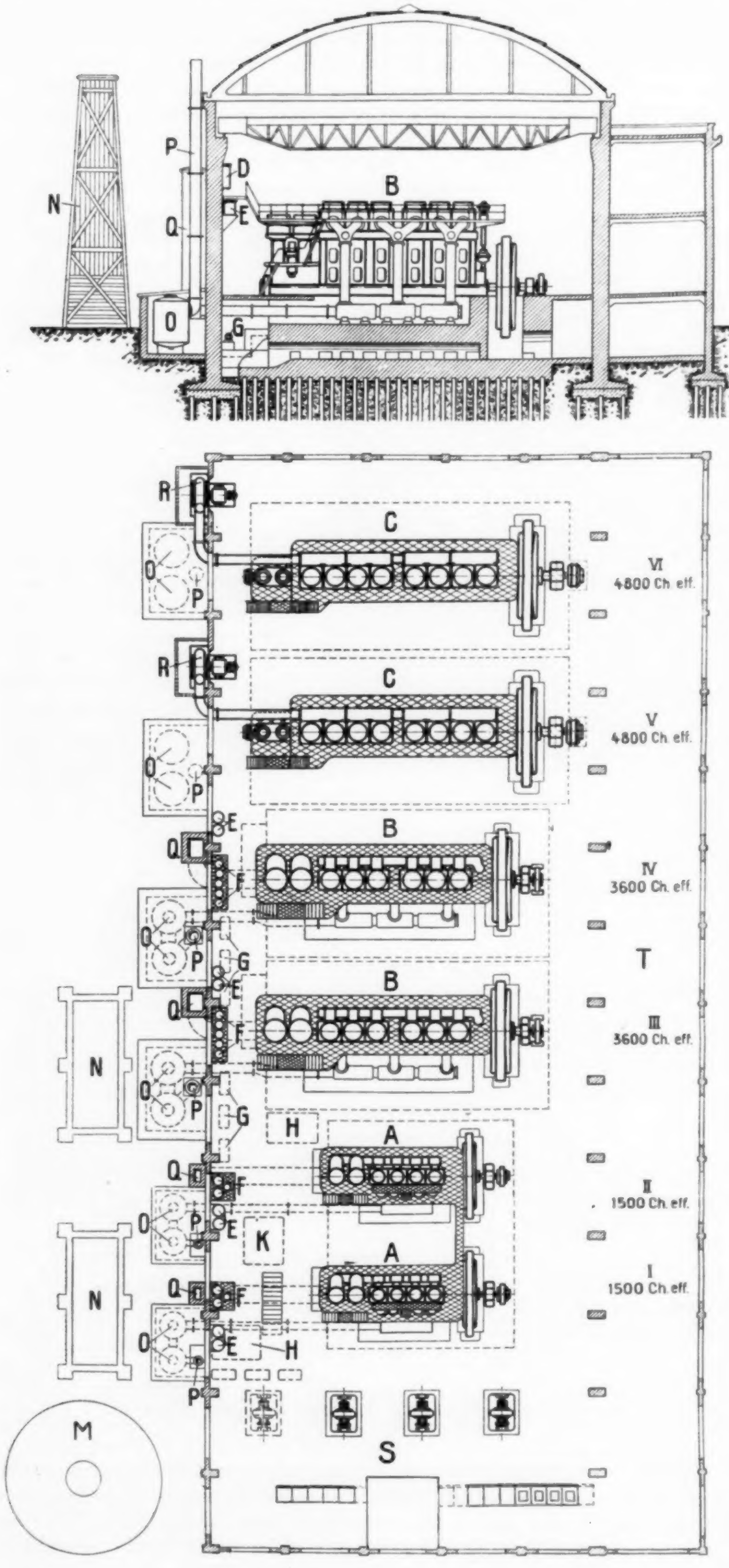



Fig. 9 20,000-Hp. 6-Unit Sulzer Diesel Plant Installed at Shanghai, China

A—1200-kva. group (1500 hp.); B—3300 kva. group (3600 hp.); C—4600-kva. group (4800 hp.); D—fuel tank; E—fuel wells; F—compressed-air bottles; G—electric pumps; H—settling tank for piston cooling water; K—hot-water tank; M—water tower; N—cooling tower; O—mufflers; P—exhaust piping; Q—suction air pipe; R—turbo-blowers for scavenging air; S—rotary converter substation; T—switchboards.

summation of such plans. This hazard has now been eliminated by the very extensive building of large marine engines, advantage of which will no doubt be taken by engineers in charge of superpower development, embracing both steam and hydroelectric power plants, with its network of distribution lines.

So far, in dealing with this subject, the use of the large Diesel engine by public utilities has been alone considered, and this is by far the largest field. To what extent the large Diesel is adopted by industry depends to a great degree on the attitude toward it manifested by the public utilities.

### Industrial Diesel Installations

If the large Diesel-engine installation has merit as a low-cost power producer it cannot be stifled, for the simple reason that industrial plants will be able to produce their own power with large Diesels at lower costs than central-station power companies can afford to supply it. Already the greater number of American Diesels of medium size—1000 to 2500 b.hp.—are installed in private industrial plants. One of these plants at the Moctezuma Copper Co., Nacozari, Son., Mexico, consists of two 2200-hp. and four 1250-hp. engines supplied by the Nordberg Manufacturing Company. At the end of 1924 this plant was reported, after some of the units had seen five years of service, to have a record of gradual reduction in maintenance cost and entirely successful operation. Investigation over a period of years of the operating results of similar engines within this range of sizes recently led the Commerce Mining & Royalty Co., of Cardin, Oklahoma, to install a 6750-hp. Nordberg Diesel plant consisting of three 2200-b.hp. engines. The installation of such plants in industries which are or should be customers of public utilities discloses a competitive situation for a long time existing to some extent between Diesel-engine builders and public utilities that is very unhealthy.

Because the Diesel engine was for many years built only in small sizes, its field was limited to small plants, both small city power-generating stations and small industrial private plants. With the development of the superpower idea, especially during the last ten years, the Diesel engine, in the minds of public-utility-power salesmen, has become definitely connected with the so-called "isolated power plant." Compared with selling electric power to replace simple non-condensing steam plants, replacing small Diesel isolated power plants has been very difficult because of the low operating costs. The electric-power salesman meeting the Diesel-engine salesman in competition for new small power plants has come to regard the Diesel as an enemy to be fought at every turn—as a menace to successful high-line development. In some cases unfair adverse claims have only served to arouse interest in the extremely low costs of producing power with Diesel engines; and in some localities the public utilities have been harassed by unfair business methods used in promoting the sale of small Diesels.

Undermining existing investment of public utilities giving good service at fair rates by agitations directed toward the installation of municipal Diesel-engine plants is economically unsound; but the menace of so disturbing comprehensive rate systems embracing large territories served by single public-utility holding companies is increasing. Fighting between two industries is usually costly to both. The great power business of the country is well organized by advantageous national electrical associations, while the thirty-five or more Diesel-engine builders are without any organization at all. The easy method for applying corrective measures would therefore seem to be, first, for the public-utility interests to promulgate proper views which would discourage costly and useless inter-industry fighting between electric-power and Diesel-engine salesmen, and, second, by installing the Diesel engine where fuel and other conditions justify the use of the Diesel, thus robbing the unethical Diesel salesman of his offensive weapon of comparing the low cost of Diesel-engine power with higher cost of steam power on which electrical rates are based. If a central station generates all or part of its power with Diesels, the principal reason for installing a municipal Diesel plant in competition is lacking; and the same line of argument applies to the isolated industrial plant.

While the Diesel was built only in small sizes this procedure could not be undertaken, but now that large units are available, the way is open. In all fairness to the merits of the Diesel engine the American power-plant engineer should give more consideration to the large Diesel, not only because of its high thermal efficiency but for other qualities which it possesses which commend it in sizes of 5000 and 10,000 kw. for installation as part capacity of even the largest power plants.

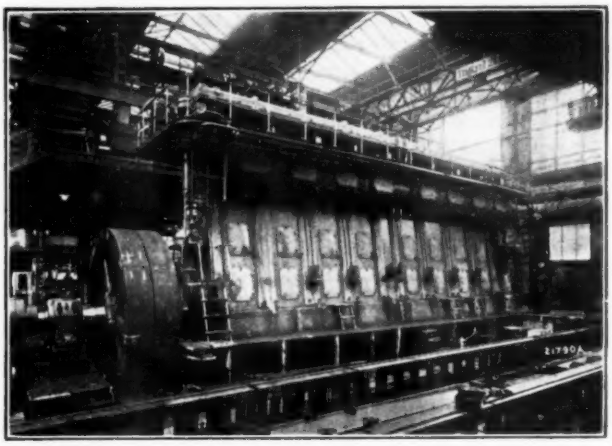


Fig. 10 Test-Bed View of 5250 B.Hp. Sulzer Land Engine, Electric Generating Station, Shanghai, China

## Discussion

Edgar J. Kates.[2] Attention has been called to the many points of contact between the local Diesel power plant and the electric central station. Referring to the fact that the greater number of American Diesels in the size range of 1000 to 2500 b.hp. are installed in private industrial plants, the author remarked that "the installation of such plants in industries that are or should be customers of public utilities discloses a competitive situation for a long time existing to some extent between Diesel engine builders and public utilities that is very unhealthy."

Certainly, oil-engine builders do not wish to stand in the way of sound economic progress. Economic laws are bound to prevail in the end, and the sooner they are allowed to come to fruition, the greater will be the benefit to all.

It therefore seems pertinent to inquire into the real function of the electric central station. Is it desirable from the standpoint of the people at large that all industry should as soon as possible receive power from centralized public utilities? Or, on the other hand, are there certain inherent limitations attached to central-station service that sometimes make a local individually owned power plant more desirable as a matter of public policy? The question of course is independent of any selfish interests. It includes other factors besides those involved in a mere investigation as to which kind of power the industrialist can buy the cheapest. In effect the question is, "How can the electric central station best serve the community?" The excuse for discussing it at this

[2] Consulting Engineer, New York, N. Y. Chairman, Oil and Gas Power Division. Mem. A.S.M.E.

time is its intimate connection with the economic future of the Diesel engine.

When the public sale of electricity was started, over forty years ago, the sole purpose was to furnish current for lighting, and for many years over 90 per cent of the current was thus used. In those days a central station's load curve showed two peaks, one of short duration in the early morning, and the other a longer one persisting through the late afternoon and evening. During the rest of the day a large part of the generating capacity was idle.

Subsequently, certain developments in the industrial field and in electrical technic, such as the improvement of electric motors and the application of alternating current to long-distance transmission, offered a solution to the problem of filling up the valley between the morning and evening peaks in the load curve. Thus commenced the eager quest for industrial power load which is still vigorously under way. This type of load was exceedingly attractive, as it made use of generating equipment otherwise idle and incurred only a small additional operating expense consisting mainly of the extra fuel. Most of the private steam plants were thermally inefficient, and the electric central station could easily afford to produce and deliver power to them at a lower price than they could make it.

Because of these advantageous factors the search for industrial power load was completely successful, and eventually the day-time valleys in the load curves of the various central stations were quite filled up. But now the pendulum has swung to the other side, and in most public-utility systems it is the industrial power load instead of the lighting load that causes the peaks and necessitates the expenditures for extensions. The industrial load is no longer a byproduct, and a correct cost analysis must allocate to it a fair share of the overhead charges.

During this period of substitution of central-station electricity for private steam-power plants the modern Diesel engine has been developed, and it has now reached a place of great economic significance. The Diesel power plant for private use enjoys the tremendous advantage over the corresponding steam plant of being highly efficient even though small. Consequently, the private Diesel plant can produce power at low cost.

Though a modern steam central station burning cheap coal *generates* electricity very cheaply, the cost of transmission makes the *delivered* cost much higher. Statistics for the United States show that the investment in transmission and distributing systems exceeds by a considerable amount that in the generating plants themselves. Furthermore, upkeep and operating costs for the distribution agencies are high, and an average of about 20 per cent of the energy transmitted is lost.

For these reasons, central stations are unable to deliver power to many types of industries at as low a cost as the power user could obtain from a Diesel plant of his own. Of course, electric power is often sold at a price which does not correspond with cost. That is because, under the system of public-utility regulation followed in most of the states, there is no obligation or even an incentive for central stations to segregate their loads into classes, determine the cost of serving each class, and apply rate schedules in accordance therewith. On the contrary, the fact that some classes of load, such as the domestic consumers, are practically non-competitive, provides an inducement to discriminate against the residence customer in favor of the industrial power consumer who can make his own energy if he wishes. With the present system of regulation this practice is generally permissible, so long as the *total* income of the central station company does not exceed a "fair return."

Such discrimination is of course economically unsound, and not only the general public, but even the central stations themselves, would benefit by its abolition. Industrial power rates that are below true cost do not promote the public interest. The low rates are not reflected in the prices of the goods marketed, since if the electric rates were higher, the manufacturer could still obtain cheap power from a plant of his own. On the other hand, the public makes good the central station's loss by paying higher residence rates than necessary.

Our national economy would be served if future large reductions in the cost of central-station current should enable all our power needs to be cheaply supplied from that source. At present there does not seem to be much hope. Generating costs are not likely to be greatly lowered; fuel engineering developments may indeed further reduce operating expenses, but they will require greater capital investment and thus greater overhead charges, with little net advantage as a result. The cost of hydroelectric power is also not subject to much reduction; the efficiency of hydraulic turbines already approaches 100 per cent, and the best sites for hydroelectric projects have already been developed. Transmission costs have an upward trend, because longer lines and higher voltages demand larger investment, cause higher expense for maintaining reliable service, and bring about greater energy losses. Transmission lines are first built to serve dense and profitable loads, and are later extended into less attractive localities.

In view of these limitations, what are the proper economic fields for central-station electricity? In the opinion of the writer the most important are:

1 The delivery of cheap hydroelectric energy to industries which are so dependent upon cheap power that all other considerations are secondary and they will be built near the hydrogenerating stations; for example, electrochemical undertakings such as the production of aluminum and the manufacture of fertilizer.

2 Furnishing electric energy to industrial establishments requiring small amounts of power, in which private power plants would not be justified. Such power should be sold at rates that will yield a reasonable profit. Typical of this field are the numerous small manufacturing plants in city loft buildings.

3 The supply of current for commercial lighting, except in a few large stores and office buildings where a private power plant would be more efficient.

4 Last and most important, the supply of cheap current to the home. This field for central-station energy offers such tremendous opportunities to serve the public welfare, and at the same time afford a most profitable income to the electric companies, that it deserves far more attention than it has received.

Over 85 per cent of the homes within reach of electric-service companies' lines are now wired up and connected. Obviously, therefore, future expansion in electric service to the home will depend not so much on connecting up to more homes as on supplying more current to the homes that already are consumers. These homes use electricity almost exclusively for light; the great opportunity lies in supplying them with current for other purposes.

Electricity can and should be made a great social servant in the home, not only for lighting, but for many other conveniences, comforts, and labor-savers unique to electricity and not sufficiently availed of at present; such, for instance, as electric refrigerators, water heating, room heating, and the operation of many small but useful electrical appliances.

The present utilization of electricity in the home is absurdly small. The average consumption is only 1 kw-hr. per day, and the load factor only 14 per cent. Think of the great expansion possible. Under these conditions the indirect costs of providing service are high, and this is sometimes pointed to as explanation for the fact that the price of electricity in the home is about ten times the cost of production.

The editorial staff of *Electrical World*, after making a survey of the light and power business, pointed out that experience with well-applianced electrical homes has demonstrated that it is en-

tirely practicable for a householder to use from 12 to 20 kw. of electrical equipment consuming between 4000 and 6000 kw-hr. annually. Such domestic installations produce a very desirable load, with a fairly even demand throughout the day and night and a load factor of 22 per cent. It was estimated that an average rate of 3.52 cents per kw-hr. could be obtained for this business and that the resulting gross income would be about $3^1/_2$ billion dollars per year, which is over ten times that now received from the entire industrial motor load.

The present inadequate use of electricity in the home is due mostly to obsolete types of rate schedules, originally designed with the idea of protecting. These should be revised with the purpose of promoting increased usage. Lower prices in the higher blocks of the rate schedules will cause greater usage and bring more profits to the electric companies; at the same time the people will derive the benefits of increased electric service. Effective education must of course accompany the changes in rate schedules.

The opportunities for profit to the electric public utilities that lie in taking on more industrial power load are trivial in comparison with those in the domestic field, and any central-station capacity released from serving unprofitable motor loads can easily be utilized for increased residential service. Thus benefits will come both to the central stations and to the public.

The chief function of the electric public utilities is to make our homes happier by supplying fully those unique services that only electricity can give. By fulfilling this purpose they will not only perform their duty to society but also reap rich financial rewards.

J. D. Bowles.[3] The Tucson Gas, Electric Light & Power Co., of Tucson, Ariz., is one of our subsidiaries. During the summer months the climate is very hot, no natural stream flow is available, water is pumped from deep wells emerging at a temperature between 75 to 80 deg., fuel oil or distillate costs from 5 to 6 cents per gallon delivered, and coal costs approximately $8 per ton delivered. These conditions combined to favor Diesel operation when power-plant additions become necessary in 1914, shortly after we acquired the property. Accordingly two 500-b.hp. Fulton Diesel units were installed in 1915. These were followed up by a pair of 550-b.hp. Busch-Sulzer Bros. engines in 1918 to 1920. Then came a pair of 900-b.hp. Werkspoor engines purchased from the United States Shipping Board, at what was then considered a bargain. All these units are four-cycle and direct-connected to three-phase 60-cycle 2400-volt Westinghouse alternators with direct-connected exciters.

The load at Tucson has continued to grow; in fact, during the last two or three years it has been growing at an accelerated rate; and when the need for additional generator capacity became urgent, I recommended against any further Diesel units of less than 2500 kw. each. Accordingly a contract was let to Busch-Sulzer Bros., of St. Louis, to build an engine rated at approximately 3750 b.hp., 124 r.p.m. at Tucson, elevation of 2200 ft. Allis-Chalmers Mfg. Co. furnished the alternator, which is a flywheel type, the rotor of the alternator serving as a flywheel for the engine. This machine is rated at 3750 kva. and is served by a belted exciter using Texrope drive. This drive, by the way, has proved entirely satisfactory and permits of an exceedingly short coupled arrangement, and by belting the exciter we reduce the cost of the installation somewhat; but, mainly, the higher exciter speed provides for better voltage regulation and the use of fewer relays for the vibrating voltage regulator. The generator voltage regulator serving this entire station, by the way, is now equipped with 32 vibrating contacts.

[3] Vice-President and Chief Engineer, Federal Light & Traction Co., New York, N. Y. Mem. A.S.M.E.

At the present time the Tucson operating requirements are about 4000 kw., and we are considering the installation of a duplicate of the present big unit in the immediate future.

The two-cycle principle was chosen for this new unit to cut down on the number of valves and consequent maintenance and loss of service as well as simplified head construction. We have found economy of this unit, so far, in all-day, every-day operation to be equal to, if not better than, the smaller four-cycle units installed in the same station. We are also using a somewhat heavier grade of fuel oil in the big engine than is permitted by the smaller engines.

There is no question of the advantage in the ease of operation and our anticipated lower maintenance costs for the big units when comparing these items with the same capacity in the multiplicity of smaller units. The voltage and frequency charts with the big unit in operation indicate superior regulation to several of the smaller units running in parallel with the big unit off the line.

The air for scavenging is drawn through an air washer to clean and cool it. With a reciprocating scavenger pump the rated capacity of this washer should be about twice its rated capacity for turbine-generator cooling. Some nuisance has been experienced at Tucson with the 3700 b.hp. unit owing to the air pulsation, accompanied by a steady thumping noise, both of which carry over the country for several miles. There is a difference of opinion among those of us who have been in intimate contact with this installation as to whether the air currents and noise are caused by the exhaust or the intake, or a combination of the two. The noise is in the form of a hollow boom like beating a large drum, timed at 124 beats per min., although the scavenger pump is double-acting in effect. We are now installing some additional muffler sections on the exhaust, the muffler being in the form of a stack which can be made up of any number of sections. At the top of this muffler there will be installed a chimney with its rim 90 ft. above the ground to correspond with an adjacent steam-boiler stack.

A concrete inlet chamber has been built which will be provided with wood baffles, and the air will enter this chamber through a stack carried well up into the air. With these added facilities, I do not anticipate any further noise or air vibration nuisance. However, our next big engine is to be equipped with an independent motor-driven scavenger blower.

There are a number of interesting features in connection with our Tucson Diesel-engine installation, such as using Zeolite-softened water for spray-pond make-up; putting this spray-pond water directly through the jacket spaces rather than through the heat exchangers of a closed system; removing the traces of oil from piston-cooling water by chemical treatment and filtration; the storage, handling, and cleaning of fuel and lubricating oils; exhaust-heat reclamation in connection with the six smaller engines, and so forth.

[Since the foregoing discussion contracts have been let for a duplicate 3750-b.hp. engine but equipped with a scavenger blower driven by a 350-hp. synchronous motor, and a duplicate alternator. This second large unit will be in operation by the early part of the coming year.—J. S. B.]

H. L. H. Smith.[4] The author says much that is of interest and gives some points that are novel. There is no doubt that in these days of interconnection between power systems there would be decided merit in having Diesel-engine units capable of operating as synchronous condensers when not needed for power generation.

As to the Sulzer Bros. single-cylinder experimental double-acting two-cycle engine with a cylinder of a diameter of 900 mm. and a stroke of 1400 mm., this is a huge cylinder, and undoubt-

[4] Superintendent of Steam Power, New England Power Co., Worcester, Mass.

edly engine builders would have to experiment with construction of such size in order that the difficult problems of cylinder-head and piston cooling might be worked out by determination of facts. The author also tells of a former single-cylinder Sulzer experimental engine having a bore of 1000 mm. The author does not make it clear whether these huge experimental single-cylinder engines were constructed by the Swiss firm or by the American Sulzer firm, but presumably they were made by the Swiss firm. It would seem to the writer to be a far cry from an experimental single-cylinder engine of such dimensions to an engine with as many cylinders as ten. It is true that the author mentions that Sulzer Bros. have supplied eight 10-cylinder units averaging about 5000 hp., but such an aggregation as proposed, constituting an engine of altogether record size, would leave one waiting somewhat dubiously for the record of successful operation and satisfactory maintenance cost and service availability.

The fact that the number of reciprocating marine engines under construction exceeds the marine turbine horsepower under construction nearly two to one does not of course establish superiority of reciprocating engines over steam turbines except under the very special economic conditions of marine power, and unquestionably it is the rather special marine power considerations which establish the ratio of practically five to one for marine Diesel engines compared with marine steam turbines.

The author gives a table of fuel oil consumed in generating electric power by public-utility power plants in 1927. In this table Massachusetts is outstanding in that it consumed 9 per cent of the fuel oil used in public-utility plants of the entire country. Massachusetts is neither a cheap oil state nor a cheap coal state, but it has water-borne transportation of either fuel so far as its coast line is concerned. Its consumption of fuel oil has varied somewhat widely and rapidly with the varying factors of oil production and freight transportation, the tendency recently having been toward lowered use of fuel oil. Specific reference is made to the Narragansett station as using fuel oil, although the most recent practice at that station does not comprise the use of oil fuel.

The author gives an interesting tabulation of estimated costs of a four-unit station aggregrating 15,000 b.hp. or 10,000 kw., using as a basis the unit engine cost previously mentioned by him of \$60 per b.hp., the estimate totaling \$1,350,000, or \$135 per kw. of installed capacity. If this installation were figured on its load capacity with one unit out of service, the unit cost would go up to \$180 per kw.

The author mentions the daily peak load as difficult to provide for in central-station operation. In these days, however, the central-station field is almost entirely that of light and power, and the old-established peak loads of a few hours' duration which characterized all electric-railway stations and do still to the limited extent in which electric railway loads have not been taken over by the general electric utility supplying light and power, and which characterized the electric-light central station in former years before the development of extensive industrial peak loads, have at the present time very limited existence.

The general electric utility today has an industrial peak load which now exceeds its lighting load. It is true that for a few weeks in the winter there is a serious overlapping, but seemingly at present it must be handled by short seasonal operation of otherwise obsolescent reserve equipment. In a few more years it undoubtedly will be handled largely by the joint effect of temporary curtailment of the heat economy of steam plants by the cutting out of perhaps two stage heaters in multiple-stage heating turbo-generators, thus allowing nearly the full throttle steam admission to go through to the condenser, the low temperature of cooling water in the winter season enabling the condensers to maintain good vacuum and also making available extra thermal capacity of generator air coolers so that the generators may carry loads from 10 to 15 per cent in excess of nameplate ratings.

The author refers to the commercial strife between Diesel-engine salesmen and electric-utilities salesmen with respect to industrial installations. More responsible consideration of the whole matter of the competitive field of electric-utility power supply and industrially generated power would seem to be free from considerations of this nature. The electric-utility industry should not be considered as antagonistic to Diesel engines, nor on the other hand can it be expected to adopt it as a means of forestalling competition with industrially generated power by means of the Diesel engine.

Joseph Pope.[5] This meeting has gone from an oil-engine meeting to a meeting of an entirely different character; its chief object now being, apparently, to criticize the central station and to find fault with the steam plant. A steam plant is not necessarily the inefficient and disreputable thing we have been told it is, and one can be built today that very closely approaches the efficiency of a Diesel generating station. Much of the discussion has had to do with the low efficiency of a steam plant with low load factor, and the suggestion has been made that the peak load be taken off with an oil engine, leaving the remaining load at higher load factor on the steam apparatus. Now a steam plant usually has a pretty well defined economy characteristic. If energy generated be plotted against fuel burned for a great number of periods of equal length but different outputs, the resulting locus is practically a straight line, crossing zero output at something more than zero fuel consumption. Practically every kilowatt-hour generated, after the combustion of this zero load fuel, bears the same fuel cost as every other kilowatt-hour. What is wanted is to get the average cost down as close to this fixed increment cost as possible. Any one who has ever run a power plant knows that, except under the most unusual circumstances, the average fuel rate on the peak watch, with lowest load factor, is always better than on the other watches. It is because there are more kilowatt-hours to divide the no-load fuel by. It is the big divisor we are looking for, and anything that results in increased kilowatt-hours helps, be it high-load factor or high peak. With the same peak the higher load factor of course wins. Load factor in itself means little in operating costs, but it means a lot in unit fixed charges.

The author refers in his paper to the cost of a Diesel plant which he estimates at \$135 a kilowatt. He also speaks about the Miraflores plant. I had hoped that he was going to tell us what it cost. There has been a great deal published about that plant, but I have never seen even a suggestion of its cost. I presume we know what the engines and generators cost, for the competitive bids were published and \$94 per kilowatt was the low bid. A statement of the completed plant cost would be very helpful to others contemplating a relatively large plant and would clear away much of the fog that surrounds estimates of plant cost.

I think that it will be generally acknowledged that oil engines and generators alone will cost \$100 a kilowatt, and that is only where you begin. If all the other necessary things can be supplied and constructed for \$35 a kilowatt, fine!—but I doubt the ability to do it very much.

The author also shows a layout of a steam station compared with an oil-engine plant. If any one were to actually build a steam plant like the one pictured, it would be the last job he would ever do for me. The capacity is 20,000 b.hp., less than 15,000 kw., and there are four turbine-generators and either seven or fourteen boilers, I cannot make out which. What

[5] Consulting Engineer, Stone & Webster, Inc., Boston, Mass. Mem. A.S.M.E.

really should go into the plant depends on the load, its present characteristics, and what they are expected to be in the future.

At most, three turbines would do, possibly only one or two, and four boilers would certainly be enough. In some cases I migh put in only two boilers, if an increase in load would warrant another in a relatively short time. You can readily see what a difference reductions like that would make in the cost of the steam plant. The same liberties cannot be taken as legitimately with the Diesel-plant equipment because the units that have been proposed are at least as large as any ever built in this country.

Referring again to the matter of peak-load capacity. There are two ways ordinarily used for providing it. The more usual is to employ old apparatus that has been in the plant for years. Its first cost was low, and it owes the plant very little now, yet it is amply good for operation on short peak runs and is just as good as anything else to stand idle for reserve. Another way now rapidly becoming popular is to buy apparatus with best efficiency points at low ratings but with large overload ability. This extra capacity can be obtained very cheaply. This is the plan being adopted by the central stations most affected by the sudden short notice demands to which the author refers. In case of such a load being thrown on the plant nothing has to be started up. The reserve capacity is already running.

I cannot see much to the idea of using an oil engine for peak purposes. I think that if an installation of an oil engine can be justified at all, it will be run practically on base load to make use of its one major advantage, economy of fuel, to the greatest possible extent. The only possible excuse for doing otherwise would be a marked disproportion in the cost of steam and Diesel fuel and a high maintenance cost for the oil engine. I doubt very much if the former would occur in this country. Perhaps it does in Germany, where, as one of the previous speakers in justifying the peak load Diesel in Hamburg has said, coal costs 63 cents per ton and oil 11 cents per gallon, although my information is that Diesel oil costs there 120 marks per metric ton (1.36 cents per pound or 8.75 cents per U. S. gallon) and coal 22 marks per long ton or $5.50 per 2240 lb.

I do not want it inferred from these remarks that I am not favorably disposed toward the Diesel engine. I recognize certain legitimate fields for it, and think it would make more progress if its proponents confined their efforts to advertising its undoubted good features instead of trying to point out the defects of other systems of power supply, concerning which they do not appear to be particularly well informed.

### Author's Closure

The comments of Mr. Edgar J. Kates throw a very interesting sidelight on the discussion. After all, the case between centralized public utilities and local individually owned power plants rests upon selfish interests; but the selfish evaluation of the relative advantages and disadvantages must, in each case, be based on more intelligent and broader considerations that the mere comparative cost of purchased power and individually generated power; at the very least, reliability and permanence of service and the effect upon other correlated uses must be considered as factors. The author had intended to point out some avenues, opened up by the Diesel engine, through which the centralized public utility could reach lower power costs, to the mutual advantage of itself and the public. Mr. Kates directs attention to another avenue to the same goal; that is, the building up of domestic load. But the intelligently selfish interests of all parties must be served, if such advantages are to be realized.

The gratifying experiences of the Tucson Gas, Electric Light & Power Company, described by Mr. J. D. Bowles, could surely be extended to many other public-service stations similarly situated. The steady growth of the unit and total capacities of this station is an indication of the development of Diesel engineering in the United States during the last 14 years. In this connection it may be of interest that, in 1912, when the plant of Busch-Sulzer Bros. was built, that company considered itself quite optimistic in assuming the largest unit it should be prepared to build to be 1500 hp.

The following will answer some of the questions in Mr. H. L. H. Smith's discussion. The large experimental single-cylinder Diesel engines, both the single and the double-acting, were constructed by the Swiss firm of Sulzer Bros., in Winterthur. The author is not in accord with Mr. Smith's belief that it is necessarily a long step from a single-cylinder experimental engine to a unit comprising ten or more of such cylinders. It all depends upon the purposes of the experiments, and the extent to which and conscientiousness with which they are carried out. Experiments started and carried out with the purpose of proving the correctness of an accomplished engineering design must not be classed with such as have the purpose of developing a piece of apparatus, and "working the bugs out of it" before introducing it to the public. The years of successful service of the many children, quadruplets to dectuplets, of Sulzers' large single-cylinder, single-acting experimental engine are a tribute to that firm's Swiss thoroughness. As to the utility of marine Diesel engines as indices of what may be expected from similar units in stationary service, while there are certain differences in the economies effected, the success of these marine engines, mounted on relatively unstable foundations, running at all sorts of angles, with propellers alternately overloaded and unloaded by waves, and developing full power continuously for weeks at a stretch, is certainly sufficient assurance of their reliability in the comparatively favorable stationary service. The multiplication of cylinders is a definite tendency of the time, with much in its favor, particularly in the matter of first cost, and little against it other than comparative unfamiliarity with the idea. It is not many years ago that even six cylinder engines met with considerable opposition from purchasing engineers for land stations.

Mr. Joseph Pope questions the author's estimate of the cost of a Diesel plant. He mentions that for the Miraflores plant the low bid on the units alone was $94 per kilowatt, and suggests that a statement of the complete cost of that plant would clear away much fog. In the writer's opinion, the opposite would result, and as an example of the unreliability of figures by themselves, the writer points out that the bids on these units included delivery at the Panama Canal Zone, many special engineering requirements, six months' supply of lubricating oil and ten months' services of erecting engineers, besides special shop tests and the expenses incident to governmental inspections and approvals. The station itself may compare with an ordinary commercial station about as the Lincoln Memorial does to the adjacent Munitions Building.

The writer is certain of the sympathetic concurrence of all builders of large Diesel engines in his assertion that they would be happy could they always get the estimated $60 per b.hp. for such stationary machines, built in the best commercial manner; and Mr. Pope will be able, on inquiry, to obtain prices on large Diesels with generators alone at less than $90 per kw.

As to the capacity of units and the resulting dimensions of stations, there is undoubtedly some economic limit to unit capacity; but looking back over only the last ten or fifteen years, who has the courage to set this limit for either steam turbines, or boilers, or Diesel engines? It was possibly unwise for the author to compare stations of equal flexibility as well as capacity, but he still contends that Diesel stations occupy less space than comparable steam-turbine stations.

# Oil-Spray Research at Penn State

By P. H. SCHWEITZER,[1] STATE COLLEGE, PA.

AN EXPERIMENTAL investigation of the fuel-injection phenomena is one of the major projects of the Engineering Experiment Station of the Pennsylvania State College. The main object of the investigation is to establish the laws that control the characteristics of oil sprays in compressed air under various conditions encountered in the injection type of oil engines.

The investigation began in 1924, and the past four years were almost entirely taken up with the building of the elaborate apparatus used in the investigation. The U. S. Navy and several engine builders helped generously in the assembly of the experimental equipment, which is perhaps unexcelled anywhere for the studying of fuel injection. The completion of the experimental program will help materially the futher development of the oil engine. Advance is expected in these two lines:

1 A more efficient introduction of the fuel
2 Its faster preparation for ignition as required by high-speed engines.

Fig. 1 shows the schematic arrangement of the set-up. The central part of the apparatus is the pressure chamber. The chamber is filled with air and oil is injected into it. The spray is observed visually through a plate-glass window which is kept free from oil fog by means of a window wiper. Illumination is provided through a similar window on the other side of the chamber. The penetration and energy of the spray are accurately determined by the pendulum shown in the middle of the chamber. The spray hits the disk of the pendulum, which deflects under the impact. The pendulum carries a small mirror at the top which reflects a beam of light through the top window, and the deflection is read on the scale above the chamber. An air-pressure gage and a safety valve, set for 520 lb., are ndicated on the diagram.

Both cam-actuated and automatic nozzles are used for the injection of the fuel. The diagram shows the set-up for constant-pressure injection. A long-stroke pump produces pressures up to 10,000 lb., which can be kept fairly uniform with an accumulator, partly filled with air, in the fuel line. Passing an oil filter, the fuel travels into the cam-actuated nozzle. A cam driven by electric motor and acting on a lever arm periodically opens and closes the needle valve, producing intermittent injections. Through a gearset the frequency of the injection can be varied, and by means of an interrupter mechanism either one shot or several in succession can be produced at will. The oil-pressure indicator records the pressure fluctuations during the injection. With the spray stroboscope, which permits the jet pass in a certain phase only, the "time distribution" of the spray may be studied.

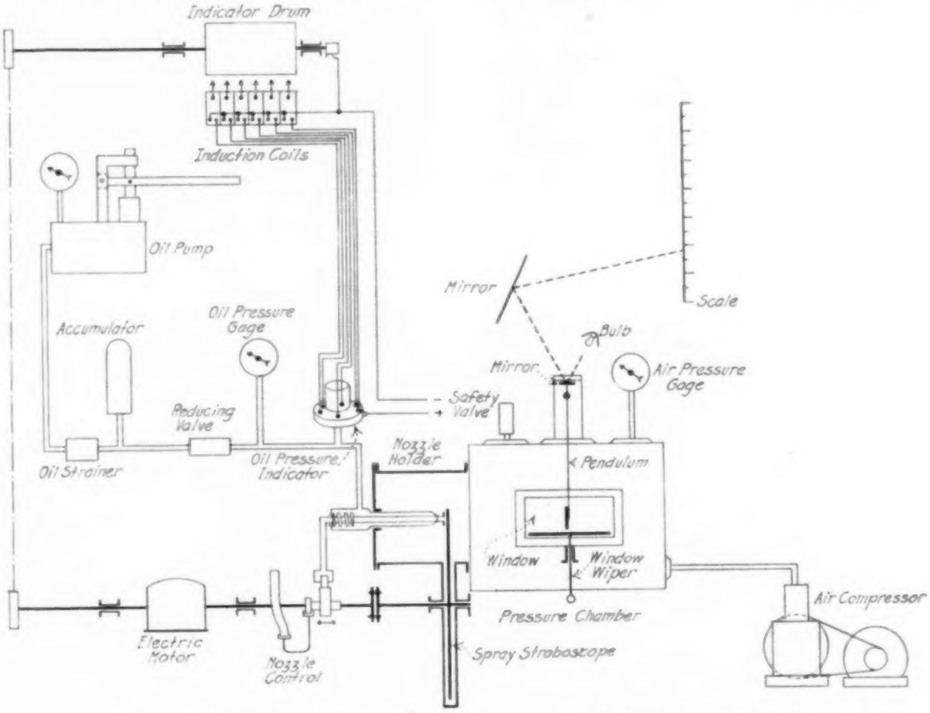



Fig. 1 Schematic Arrangement of Equipment for Fuel-Spray Research

With jerk-pump injection an automatic nozzle is placed in the nozzle holder in place of the cam-actuated nozzle and a fuel pump is driven by the cam. In this case the hand pump, accumulator, and oil-pressure gage are out of operation, but the interrupter acts on the pump itself producing one-shot injection.

Fig. 2 shows the pressure chamber, which is a rectangular casting with 28 in. × 20 in. × 20 in. outside dimensions and $2^1/_2$-in.

[1] Associate Professor of Engineering Research, Pennsylvania State College.

Presented at the First National Meeting of the A.S.M.E. Oil and Gas Power Division, The Pennsylvania State College cooperating, State College, Pa., June 14 to 16, 1928.

wall thickness, tested for 800-lb. hydrostatic pressure. The plate glass windows are 1 in. thick and are clamped between rubber gaskets in a floating manner to eliminate the initial strains. The seal is effected by the internal pressure only. The entire chamber moves on rails, which permits the study of various jet lengths. To vary the distance between the nozzle and the pendulum spacers are used.

The experimental nozzle, Fig. 3, used for constant-pressure

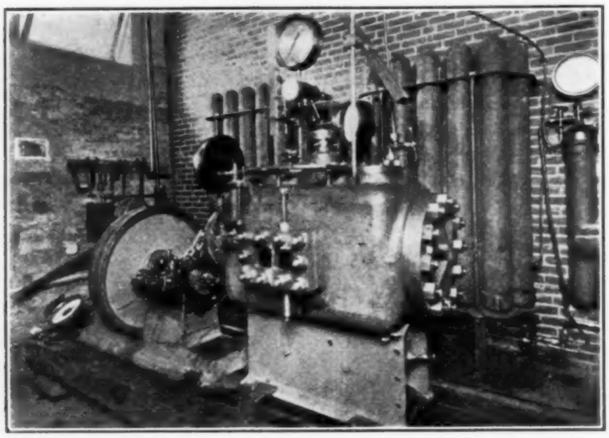


Fig. 2 Pressure Chamber to Study Spray Characteristics

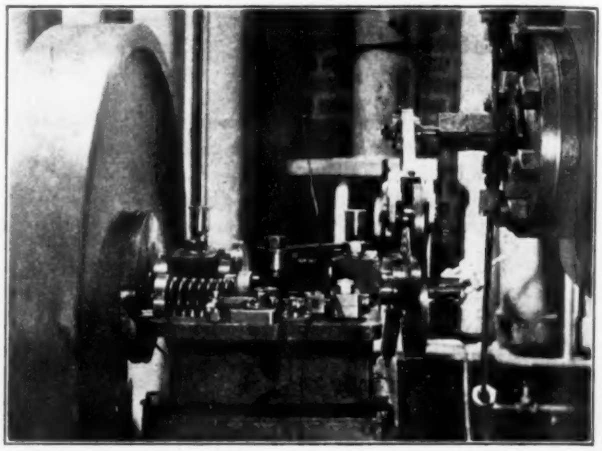


Fig. 4 Injection Interrupter to Produce Single Injections

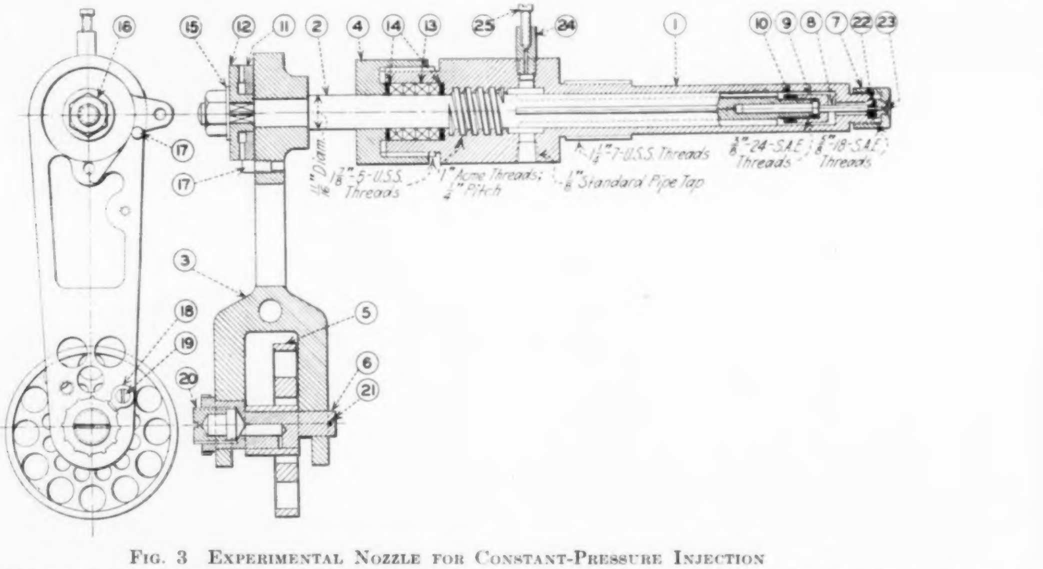



Fig. 3 Experimental Nozzle for Constant-Pressure Injection

(1 Valve body. 2 Valve spindle. 3 Valve arm. 4 Stuffing nut. 5 Roller. 6 Roller pin. 7 Nozzle cap. 8 Needle valve. 9 Valve holder. 10 Lock ring. 11 Clutch, female half. 12 Clutch, male half. 13 Packing material. 14 Washer. 15 Washers. 16 Nut. 17 Pin. 18 Roller-pin stop. 19 Screw. 20 Plug. 21 Cotter pin. 22 Valve seat. 23 Nozzle tip. 24 Vent. 25 Vent screw.)

injection, is built on the screw principle and has proved very satisfactory. The object of the unconventional design was to be able to use large cams in conjunction with small needle lifts. In this way the influence of the cam profile can be studied more conveniently. Both flat seats and conical seats are being used. With the injection interrupter, Fig. 4, single injections can be produced at a high rate of speed. The cam rotates continuously, but ordinarily it is out of engagement with the roller of the lever arm. By tripping the trigger, shown in front, the cam moves axially and stays in engagement with the roller for one revolution only. In this way a one-shot injection is produced. Setting the interrupter out of action, the injection repeats continuously.

The spray stroboscope, Fig. 5, is an aluminum disk with a slot and is driven from the same shaft which controls the injection. It is located between the nozzle tip and the pressure chamber. The slot permits the passage of the jet at definite intervals only. The rest of the spray is kept from entering the chamber. By corresponding angular adjustment of the disk, various phases of the injection, such as the beginning, the middle, or the end, can be separately studied. By measuring the amount of oil injected in the first, second, and third periods and determining the energy and penetration of various phases by means of the pendulum, the time distribution of intermittent sprays is studied and valuable information regarding after-dribbling is secured.

The dispersion or space distribution includes such items as penetration, cone angle, and spray density at various points. Absorbing the spray with felt rings made up from proper sections and determining the amount of the liquid absorbed by the weight increase is the technique to be used in studying these problems.

In order to record the pressure variations in the injection line during the short time of injection, a special indicator, shown in Figs. 6 and 7, has been developed.

The main principle of the indicator is the use of a number of pressure-registering elements instead of a single one. Each of the six diaphragms is set for a different pressure, and at the instant the pressure reaches a predetermined value, electric contact is made which is recorded on a rotating drum. The contact is maintained as long as the pressure exceeds that for which the diaphragm is set and during that time the corresponding spark needle on the drum punctures the paper at each spark, producing a row of holes. In this way a number of perforations are produced, the length of each corresponding to the time interval during which the pressure exceeds the pressure for which the respective diaphragm is set. Using six diaphragms, which deflect at, say, 200, 400, 750, 1200, 2000, and 3000 lb. per sq. in. pressure respectively, twelve points are obtained, six for the ascending and

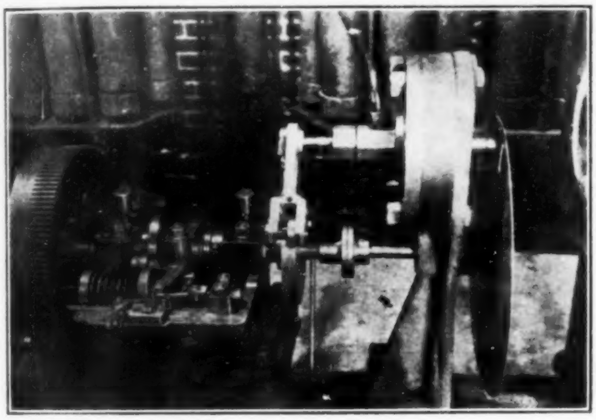


Fig. 5 Spray Stroboscope to Study the "Time Distribution" of the Injection

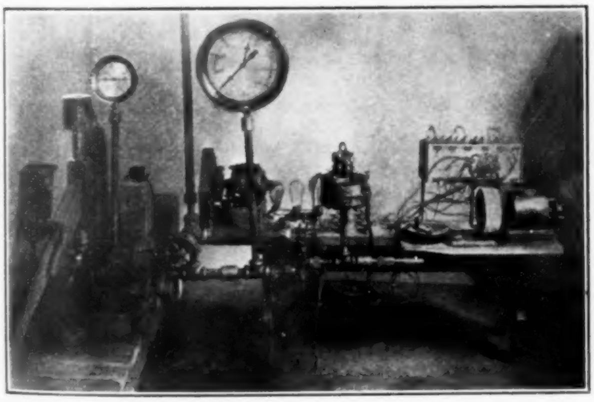


Fig. 6 Assembly of Oil-Pressure Indicator

six for the descending curve, indicating the time at which these pressures were passed during the injection. The connection of these twelve points into a continuous curve, giving a time-pressure diagram, offers no difficulty.

The recording is practically instantaneous. The electric lag—that is, the time interval between the contact made in the indicator and the mark produced on the paper—was measured and found to be about 0.0002 sec. Because the movement of the diaphragm is but a few thousandths of an inch, the inertia effect is negligible. With this indicator pressure variations of several thousand pounds within less than one one-hundredth of a second have been recorded and time-pressure diagrams obtained. Fig. 8 shows the oil-pressure indicator mounted on an engine with a duplicate spray nozzle.

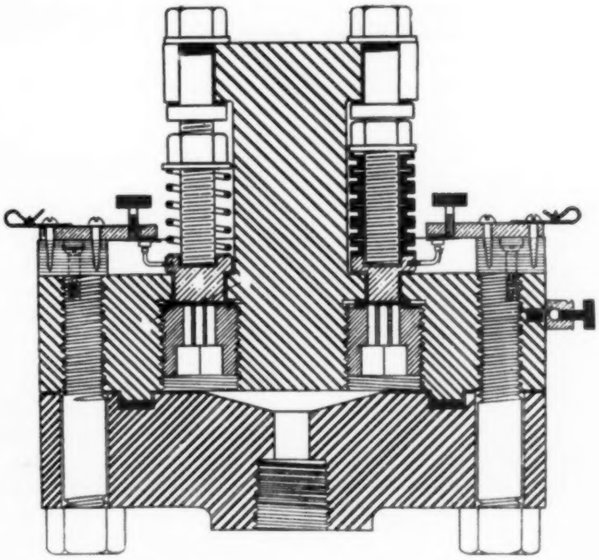


Fig. 7 Cross-Section of Oil-Pressure Indicator

Standard tests are proceeding now in three different lines: 1 Continuous injection under constant pressure. 2 Intermittent injection under constant pressure. 3 Jerk pump injection.

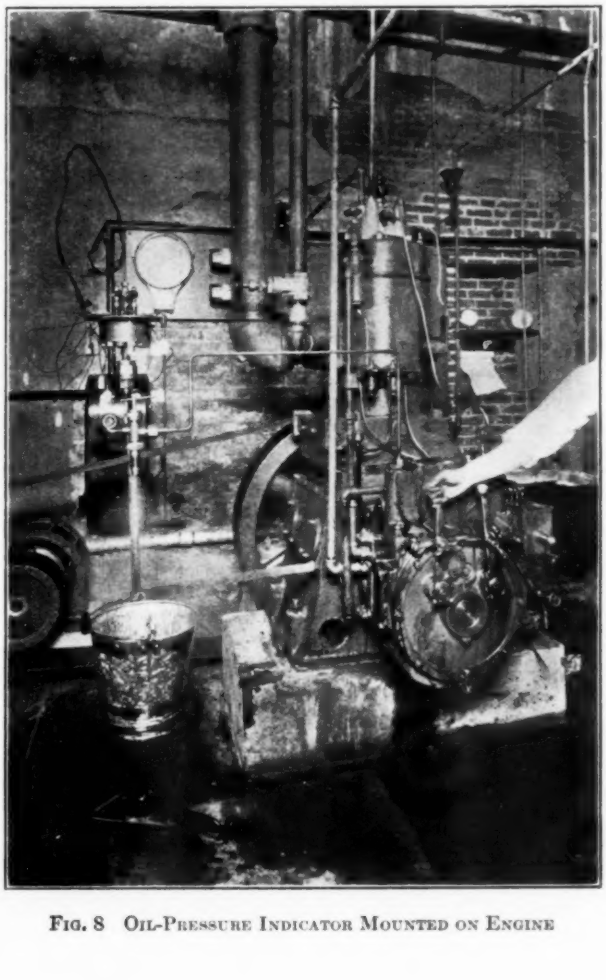


Fig. 8 Oil-Pressure Indicator Mounted on Engine

The characteristics being investigated are: 1 Spray penetration 2 Spray dispersion. 3 Time distribution. 4 Pressure fluctuations. 5 Injection lags.

The factors influencing these characteristics which are investigated are: 1 Oil pressure. 2 Pressure or density of the gaseous medium. 3 Orifice dimensions. 4 Properties of the fuel. 5 Frequency of injection. 6 Cam profile. 7 Length and diameter of the pipe line. 8 Injection pump characteristics. 9 Turbulence.

Penetration tests with continuous sprays are made by the zero method. The pendulum is loaded with a weight which just keeps it in balance against the deflecting force of the spray. If the balance is slightly disturbed, the light indicates it on the scale.

Penetration of intermittent injection is measured by the one-shot method. The pendulum acts as a ballistic pendulum in this case, and the energy of the spray is inferred from the amount of deflection. The dispersion or space distribution of continuous and intermittent sprays is determined by the felt-ring method and the time distribution of intermittent sprays by the spray stroboscope.

Paralleling the investigation of the external spray characteristics, pressure variations within the nozzle and the pipe line are studied and correlations established. The electric-spark method is also used in the investigation of the time lags, so important with the jerk-pump injections.

The project is planned to include the testing of commercial fuel-injection equipment.

OGP-50-13

# Specialization in Manufacturing Diesels

By O. D. TREIBER,[1] CAMDEN, N. J.

A MANUFACTURER is always hunting ways to cut costs, and the purchase of finished specialty products is perhaps one of the principal ways to do this. The automotive industry could not have developed to its present state without the ability of manufacturers to buy specialty finished products, although some of the automotive concerns have now grown to such a size that they manufacture many of their own specialties.

The Diesel-engine industry has today a very good supply of specialty products to draw from such as bearings, piston rings, drop-forgings, castings, crankshafts, valves, cams, springs, pistons, gears, governors, lubricators, pumps, gages, and valves, all of which are more or less common to many builders of engines. Prices of these products to the manufacturer are in many cases very satisfactory and such as to discourage the engine builders from trying to manufacture them. However, there is opportunity for improvement.

The Diesel-engine business is settling down to a more stable and well-organized business. The ability to obtain specialty products from various shops will undoubtedly have a bearing on the reduction of Diesel-engine costs and should be encouraged. There will undoubtedly be different designs of items such as fuel-oil pumps and spray nozzles. However, these generally fit about the same tools, and shops should organize themselves for producing such things, even in small quantities. At fair prices they can reasonably expect to be quite successful. There may be some parts which an engine builder can manufacture in his own plant cheaper or better than can be done in a specialty shop. This, however, is doubtful if the specialty shops will make a study of requirements and equip themselves for economical production.

The various parts of the Diesel engine can be classified into a reasonable number of groups, such as parts which are hardened and ground, parts made on screw machines, automatics, parts made from small iron castings, parts made from large cast-iron castings, parts made from aluminum. Another item is piston rings; still another is bearing shells. Another separate classification could be cylinder heads and liners. Under these classifications can be grouped practically all the parts entering into the construction of Diesel engines. It would seem to me, as an engine builder, that this section of the A.S.M.E. would contribute a factor of tremendous economical value by appointing a committee to study these classifications and make recommendations with a view to assisting both engine builder and specialty manufacturer in the economies which might be effected from specialty manufacturing.

It is necessary of course for the specialty manufacturer to study the needs of the engine builder and make what the engine builder wants and under no circumstances endeavor to sell the engine builder something which the specialty man for selfish reasons has become interested in selling.

Progress in the Diesel-engine building art has been very rapid in the last few years, but production will never be as intensive as in the automotive business. However, specialty shops can contribute their portion to the economics of Diesel-engine construction in maintaining a high-class organization of mechanics who are taught to do different kinds of jobs economically. This policy is of necessity exercised in the Diesel-engine manufacturer's shop because of the lack of high production of any given size, and if it can be worked out efficiently in the builder's plant it can also be done in the specialty shops. Take, for instance, the matter of spray nozzles. There are probably twenty-five different kinds of spray nozzles today built in as many different shops. Probably there is not sufficient production in any one shop to tool up for high production. However, should the construction of all of these spray nozzles be confined to one shop and one organization, there are a great many of the operations, such as heat treating and grinding, assembling, testing, etc., that could be done much more economically, resulting in larger savings to the ultimate purchaser.

[1] President and Chief Engineer, Treiber Diesel Engine Corp. Mem. A.S.M.E.

Presented at the First National Meeting of the A.S.M.E. Oil and Gas Power Division, The Pennsylvania State College cooperating, State College, Pa., June 14 to 16, 1928.

OGP-50-14

# The Diesel Engine and Public Utilities

By ROSWELL H. WARD,[1] NEW YORK, N. Y.

THE problem of the relationship between the Diesel-engine industry and the public utilities is one which deserves the careful consideration and dispassionate scrutiny of all concerned. It is a matter of vital importance to the utility companies because the Diesel engine in its present advanced state of development is likely to be the most direct answer to the future challenge of low power rates, high transmission costs, and high fuel costs, conditions which every power producer is facing or must expect to face within the next few years.

To the Diesel-engine industry the subject is naturally of interest because the public-utility use of Diesel power on a large scale, given the proper appreciation of the scope and capabilities of the Diesel engine, can become an important force in extending the field of usefulness and the public understanding of the Diesel engine.

We have heard an author refer to the relations between the two industries as "unhealthy;" and it is the purpose of this paper to conduct a verbal diagnosis of this "invalid," this unhealthy condition, in the hope that some of the points brought to light may serve as a firmer foundation on which to base our future efforts in behalf of the broader application of Diesel power.

The Diesel engine industry and the public utilities are both comparatively young, and they are both "pioneer" industries in spite of the tremendous development which has taken place within the past few years.

In the sense that they are both dedicated to the greater development of our national power resources, the Diesel-engine industry and the public utilities are "brother" industries. At times they have lived and worked together with the utmost harmony; at other times they have indulged in the most vituperative family squabbles; and in some instances they seem to have carried on entirely oblivious of each other's presence. This rather erratic behavior is due to the somewhat conflicting points of contact between the Diesel industry and the public utilities, which can be summarized as follows:

1 Public utility use of Diesel power
2 Competition between the Diesel industry and the utility companies for industrial load
3 Competition for municipal projects.

The first view of such a complex relationship might lead one to believe that the questions concerning each individual point of contact should be discussed separately. However, it has been found that there is so much overlapping, especially so far as policies and trade practices are concerned, that we can broaden the discussion to include all of the underlying issues and that their relationships to these points of contact will easily clarify themselves as the discussion continues.

Looking at this relationship with a full appreciation of the fact that the Diesel engine has most conclusively established itself in an immense variety of power applications, the general sphere of which have been defined by Mr. Pollister and Mr. Pratt, we find a rather unequal allotment of this essentially American "pioneer" spirit. The Diesel-engine industry has, if anything, been a little bit overenthusiastic in some of its relations with the utility companies, a perfectly natural reaction, however, when they find great and supposedly progressive power producers apparently blinding themselves to the immense progress in Diesel central stations that has been made by European groups. The utility companies, on the other hand, have been backward in recognizing the Diesel engine as anything but a troublesome competitor for industrial load. The reasons for this condition can probably be summed up under the following three headings:

1 Unreasonable sales methods by both Diesel salesmen and utility-power salesmen
2 Lack of understanding of the Diesel engine by American engineers
3 Lack of uniformity and scarcity of Diesel-power cost records, especially of public-utility plants.

In an effort to clarify the sales methods of both industries the writer has carried his inquiries not only to all of the Diesel executives with whom we are ordinarily in contact, but through the courtesy of Mr. Paul S. Clapp, managing director of the National Electric Light Association, he has also been given an excellent opportunity to hear what the commercial power salesmen have to say about it. From the standpoint of the Diesel-engine salesmen the following practices of public-utility power salesmen seem to be the ones which arouse the most comment:

1 Inaccurate compilation of reports on Diesel power costs which are submitted as a basis for comparison with the utility companies' quotation
2 Misrepresentation of operation of Diesel engines in utility company plants and in private installations
3 Misleading statements as to future supply of fuel oil; criticism of Diesel engine manufacturers' advertising; presentation of contracts which do not clearly indicate the extent of charges, due to penalties, demand charges, etc.
4 Exaggerated statements as to the degree of training necessary for a successful oil-engine operating engineer
5 Misrepresentation of municipal and insurance company regulations for storage of fuel and lubricating oil.

The public utility men, in turn, sum up their composite criticism of Diesel sales methods as follows:

1 Criticism of public utilities as "soulless" corporations or monopolies; criticism of public-utility policies, rate structure, etc.
2 Criticisms based on differences in industrial and residence rates, etc.
3 Appeals for public ownership of municipal plants based on everything from costs to civic pride; extremely broad generalizations as to superiority of Diesel power.

In reference to the methods of commercial-utility salesmen, it must in full justice be said that most of the statements made by them are the result of ignorance. However, there is a uniformity in the utility companies' policy toward the Diesel engine which is strikingly absent in the attitude of various Diesel-engine builders.

The reason for the uniformity in utility expressions of opinion on the Diesel engine is principally the annual "Diesel Engine Cost Report" of the National Electric Light Association, a cost report which is compiled by a power committee of power salesmen and not engineers. *Oil Engine Power*, as some of you know, has set in motion an effort to obtain a disinterested technical scrutiny of the next N.E.L.A. Power Committee report, an

[1] Managing Editor, *Motorship*.

Presented at the First National Meeting of the A.S.M.E. Oil and Gas Power Division, the Pennsylvania State College cooperating, State College, Pa., June 14 to 16, 1928.

effort which has already met with considerable success, although there are several points which have not yet been satisfactorily settled.

There is a tendency on the part of the utility-power salesmen to regard this "report" as a sales manual; there is a lamentable lack of uniform and up-to-date Diesel-plant cost records, a point which will be elaborated later; there is a tendency to regard the Diesel engine from the utility viewpoint, as merely an industrial competitor. It will therefore be seen that considerable further work must be done before this report loses the "sales manual" taint and becomes an impartial report on Diesel costs.

The attitude of the average American engineer toward the Diesel engine is a stumbling block which has its roots deep in the dark ages. Realizing that the technical schools are partially, though involuntarily, responsible for the lack of up-to-date Diesel training of the average engineer, a survey of Diesel training facilities has been made by *Oil Engine Power*.

Another bad habit of the average engineer is his inclination to think only in terms of very large central stations. It is quite true that in various thickly populated areas we have extremely large central stations, but the cost of high line transmission, the comparative sparsity of the population in a great many sections of the United States, and a number of other factors have limited the construction of large central stations. Hence, the average electric public service or industrial plant in this country is comparatively small, and most of them are well within the range of Diesel power; yet our engineers insist on thinking in terms of mastodons when they are surrounded with prairie dogs most of the time.

The question of Diesel operating statistics has been mentioned; it is comparatively easy to get cost reports on private Diesel plants, although they are lacking in uniformity, but the very same utility group that will criticize the Diesel engineer for lack of a mass of uniform statistical data will be the first to refuse to release the cost data on its own Diesel plants.

Statistics are the basis of any impartial engineering survey; and until there is a mutual agreement on such points as rates of depreciation, interest rates, charges for maintenance, cost of installed capacity, etc., and a mutual interchange of data on private and public utility Diesel plants, Diesel statistics will continue to suffer from varying interpretations and from the limitations of the sources from which they are drawn.

If we will therefore return to the first analysis of the contacts between the utility companies and the Diesel engine manufacturers, we will find the following interrelation:

1 Concerning competition for industrial load: The natural course of business evolution and the setting up of an impartial fund of Diesel statistical data will automatically settle many of the unnecessary points of conflict which surround what should be a condition of healthy clean-cut competition. A future development along this line may be the consideration of the use of Diesel engines by utility companies themselves, who find it uneconomical to attempt to transmit power over the high line to an industrial user. If a utility company can ask an industrial prospect to install an elaborate transformer installation, it could certainly propose to the industrialist that he permit the utility to install and operate a utility-owned Diesel plant to give him the degree of reliability and economy which he has a right to expect.

2 Public-utility use of the Diesel engine is dependent on an appreciation of Diesel power which will be fostered by "cleaning up" the methods of competition for industrial load; by taking additional steps to inform graduate engineers as to the recent progress in Diesel engine design and application; by cooperating with the technical schools to bring their power plant courses up to a requisite point of "Diesel consciousness," and by gathering and disseminating broader and more authoritative cost records of large Diesel plants.

3 The question of competition for municipal plants is largely a matter of the individual policy of the Diesel engine manufacturers and public utilities concerned. Progress along the lines indicated will largely eliminate the charge of "unhealthy" methods in this market.

It will thus be seen that what appears at times to be an intricate and embarrassing conflict between two great industries is largely a series of minor misunderstandings to which a number of very logical answers immediately suggest themselves. Impartial and uniform cost reports on a large number of Diesel plants are urgently needed; a determined effort should be made to bring engineers and engineering students "up to date" on Diesel progress (a work to which *Oil Engine Power* and *Motorship* are, in the nature of things, deeply committed); and underlying all of these efforts should be a deep appreciation of the value of giving the newer business policy of cooperation between industries (even though they are competitive) a chance to prove its usefulness in this relationship.

Above all, there is the essential dedication of these two industries to a common cause: the dissemination of the emancipating lifeblood of cheap and reliable electric energy to the mass of the world's population, a tremendous and fundamental work which promises to be the greatest civilizing force ever conceived by man—a world movement in which the Diesel-engine industry and the public utilities will mutually be expected to meet the challenge of the future.

## Discussion

H. C. Thuerk.[2] We are here today not to secure information to use against your Diesel-engine industry nor are we here because we feel that by our presence we may temper some of the statements which might be made. We are here, however, because we are anxious to obtain first-hand and authentic operating information on the Diesel engine. We have been glad to work with Mr. Ward in an effort to reach a common understanding between the Diesel-engine manufacturers and our own great power industry, as we feel that we have certain common interests.

We have been trying for several years to secure authentic operating cost data on Diesel engine plants. If it were possible to have contacts in the Diesel-engine industry where we could obtain this information, I am quite sure a great deal of the present misunderstanding would be eliminated. I want to say here as a member of the power committee of N.E.L.A. that we sincerely appreciate the spirit of cooperation shown by Mr. Pollister of the Busch-Sulzer Bros.-Diesel Engine Company.

When we talk about conserving our natural resources it should be pointed out that the central stations of this country have a responsibility in this direction. We are at present furnishing approximately 60 per cent of the energy used by electrified industries. We have built up power stations, transmission lines, and distribution systems which represent a considerable investment. If large customers are taken away by competition it means that these large investments will be idle. Naturally therefore we are carefully watching all types of competition for this business in order that we may ethically protect these investments on a sound, economical basis.

It is true that the information disseminated to the electric light and power companies had been gathered by our power salesmen, but I want to point out the fact that these data are obtained from engineers. We have recently made arrangements so that one member of our power committee will attend all meetings of the oil and gas power sub-committee of the prime movers

[2] Erie Lighting Company, Erie, Pa.

committee and thus have available for our own records the data gathered by the engineers of our industry. If we can obtain from the Diesel-engine manufacturers accurate cost records on existing plants over a sufficiently long period of time, I assure you that we are going to publish that information if permission is obtained to do so.

I believe that there will always be competition between us. We shall never reach the time when members of both industries will sit back and curtail selling activities. Your industry and mine will probably always be in competition for additional power business. If we can compete on a strictly ethical basis and eliminate some of the undesirable characteristics of past experiences, I think that we shall have accomplished all that we may reasonably expect.

By cooperating we should be able to gather a great deal of statistical information on operating and investment costs which should be extremely valuable to both of us. This information will be of interest to both industries from the standpoint of competition and also from the standpoint of installing Diesel-engine units in our own generating stations.

Finally, I believe that this will be accomplished only by adopting a reasonable attitude toward each other. If we can have that reasonable attitude existing between the Diesel-engine industry and the electric industry, many of these problems will automatically solve themselves.

Hermann Lemp.[3] In my early days with the General Electric Company at Erie, Pa., I was very enthusiastic about the Diesel-engine. In connection with Mr. Henri Chatain, we completed what we considered a satisfactory 250-hp. high-speed Diesel engine, and after our work was finished we were disappointed to learn that the central stations had mentioned to headquarters that if we were to build these engines our business for central stations would cease. It occurred to me later that perhaps our sales department was at fault, and instead of advertising the fact that the small Diesel engine would be the most satisfactory unit for a small plant, it should have gone to the central station interests and told them how they might serve a much greater territory than they were serving at that time, explaining how they might establish portable Diesel-engine plants here and there, where the outlook of business would not warrant the extending of lines, substations, etc. By so doing they would create a new demand for electric service, and once this service established, feeders could then be run to take the place of the Diesel unit, which might then be moved to another unserviced territory.

I am thoroughly believing in the value of stress, and therefore think there will always be a certain amount ot honest competition between the electrical-power interests and the Diesel-engine interests. When business is operated on that basis, then the best results are to be obtained, and I believe it will be beneficial to all concerned.

Herbert W. Dow.[4] The Nordberg Manufacturing Company has many data available concerning the performance of Diesel engines in the large stations of this country. There is a plant at Moctezuma Copper Company, Nacozari, Sonora, Mexico, 9400-b.hp., which is the largest Diesel station in North America. Since this plant was put in operation seven years ago every item of cost has been recorded, and the records and the manner in which they are kept are the most complete that it has ever been my privilege to inspect.

Two 1500-kw. Nordberg Diesel generating units have been operated for the past two years by one of the largest public-service corporations in the United States. This plant has been operated on base-load service. We know what the costs of operating this station have been, and as subdivided into various items both as to prime cost and repairs. We have on various occasions asked for permission to publish this information concerning the actual costs of operating these stations, but permission has not been granted.

I personally have a feeling that the Diesel-engine builders have no right to publish such costs, for they represent vital statistics in relation to the carrying on of another industry. I am quite sure that none of us would look with favor upon having our detail operating costs in relation to the building of Diesel engines published broadcast. I believe that such data should come from users of Diesel engines, and then it would be much more authentic. We are waiting with great interest for the day when the owners of large power plants, who do know the operating costs, will either publish this information or pass it on for the benefit of the others engaged in public-service work.

Edwin H. Krieg.[5] It would appear from some of the preceding statements that there is a prevailing impression that public-utility engineers do not consider the Diesel engine. When a plant is built, it is not with the purpose of using a particular kind of prime prover, but to attain maximum financial economy. I have known of cases where steam plants were replaced by Diesels, and likewise where Diesels were replaced by steam turbines. Well-informed public-utility engineers would consider it folly to select a steam turbine where a Diesel engine would do the work better and more economically.

Statements of $135 per kw. of installed capacity and 9000 B.t.u. per kw-hr. are felt to be contradictory to values of $150 to $300 per kw. and 13,000 to 19,000 B.t.u. per kw-hr. as given in former N.E.L.A. reports. All of these glittering generalities about Diesel engines as always being the most economical lead to great misunderstanding. Greater progress would be made if the Diesel people would call to the attention of public-utility engineers the proper methods of evaluating the advantages of the Diesel in terms of dollars and cents, as there is a paucity of information and methods for such analysis.

Several speakers have referred to the data in the N.E.L.A. reports as perhaps being inaccurate. I know personally of some of the plants reported upon and am sure that the data are quite accurate.

May I again plead that the stating of generalities regarding Diesels be supplanted by an evaluation of those advantages by as accurate data as are available.

O. F. Allen.[6] When I was in Hamburg, in discussing the matter with the manager there I asked him what his comparative costs were for current from the new 130,000-kw. highly efficient plant in relation to the 10,000-kw. Diesel unit installed there. I asked him if he expected the Diesel engine to save anything over steam operation, and he said, "No." Up to that time they had no data that indicated there would be a great deal of difference in the cost, but they expected the overall cost of current produced would be a little less from the steam units.

A point that I want to bring out is with reference to capital investment and the use of capital by industrial plants. Much has been said about the industrial plant having its own installation, making its own power as compared with buying central-station power.

In the first place, the user of power wants the capital for his

[3] Ingersoll-Rand Co., New York, N. Y.

[4] Sales Manager, Nordberg Mfg. Co., Milwaukee, Wis. Mem. A.S.M.E.

[5] Assistant Engineer, Electric Bond & Share Co., New York, N. Y. Jun. A.S.M.E.

[6] Manager, Automotive Sales, International General Electric Co., Schenectady, N. Y. Mem. A.S.M.E.

own business. If you study the great railroad systems that have electrified their lines during the last few years, not only in Europe, but in this country, where they had every inducement based on previous history to put in their own plants, you will note that they have not done it; they purchase their power. In other words, the generation of power is now a business in itself.

There are many cases where industrial concerns today have a certain amount of capital, which they might use in building their own isolated plants and thereby reduce their operating costs compared with using central-station power. But they do not put in their own plant, because they can earn a larger return by putting that capital into their normal business. They figure that the furnishing of power is the other man's business and not theirs. I am afraid the Diesel-engine men going out to sell the isolated plant proposition have not always realized the economic situation.

The other point is that if that investment is made, the owners are making a larger investment and will tie up more of the world's capital, on account of the reserve capacity, spare capacity, and peak-load capacity, which for their smaller plant must be relatively larger than the central-station system which would serve them.

Arthur F. Macconochi.[7] I should like to ask a question concerning the development in this country of apparatus for utilizing the waste heat from the Diesel. We are already very familiar with the application of this principle to the large number of industrial plants which have need of heat for process water and steam as well as power and which commonly employ a steam engine or turbine. In certain cases the heat balance would undoubtedly favor the more efficient Diesel, with its entire absence of smoke. Where the plant could produce an excess of power economically, some arrangement might be made with the public utility whereby an interchange could be effected (as is sometimes done in the case of the steam prime mover) to the advantage of both parties.

R. W. Wadman.[8] The question of waste heat is a very important one as it applies to Diesel engines, and it has received a good deal of attention. There are two companies in this country that are producing an ordinary water-tube type of boiler with shut-off valves and which are connected to the exhaust outlets of the Diesel engine. I know of instances where textile plants are securing all of their process water and process heat and still turning some of the exhaust up the line.

Nordberg has a plant at Rensselaer, Ind., a big building which is heated entirely from the exhaust of a Nordberg Diesel engine. It is a very simple piece of mechanism, but it has not been very well merchandized by the manufacturers of the waste-heat generators. It can be obtained, and the application of Diesel engines to industry will grow extensively as the manufacturers of Diesel engines will learn to use waste heat and apply it to the problems of their customers.

Charles E. Beck.[9] You have heard a great deal thus far about the Diesel-engine salesman, and as I am one I believe that I can speak for him. I travel constantly over a territory comprising all of the Middle Western States and have done so since the year 1911. I am satisfied that all that has been said by Mr. Thuerk of the Erie Lighting Company and by the gentleman representing the Electric Bond and Share Company is substantially correct.

Diesel-engine builders are criticized for not having operating records of their engines, but we are refused these records by public utilities using our engines. We have some good records of municipal Diesel-engine plants, but the utilities are not inclined to give them much recognition. Some of the builders have no records of any consequence at all, and despite the fact that they have many good installations. Some of the published records are incomplete and inaccurate, and again they do not always cover a long enough period.

It certainly is not the intention of the better builders of Diesel engines to antagonize the public utilities. My company, through its representatives and officials, has endeavored to work with and to assist the utilities, lend them cooperation, and in no way to interfere with their activities. They have trained engineers in their employ who are fully capable of solving their power-generation problems. It would not be far amiss to say that so far in 1928 more Diesel-engine horsepower has been purchased throughout the West by public utilities than by industries and municipalities.

The utilities have been aggravated in the West by certain engine builders and specially organized companies that go into a community being served by a public utility and offer lower rates as well as a local Diesel-engine generating plant. A community that has suffered from interruptions in the service and possibly from abnormally high rates becomes a good prospect. No obligation attaches to the city or town, and when the net earnings of the Diesel plant have wiped out the purchase price, the plant becomes the property of the city or town. A situation of this nature does not improve the feeling of the public utilities toward the Diesel engine.

One of the largest builders of Diesel engines in the United States is back of a scheme of this kind. The contention is that the greatest volume of business comes from municipalities, and it is necessary to pursue a policy of this kind because of the rate at which towns and cities have sold out to public-utility companies. The Diesel-engine salesman receives his worst criticism for the work he does in connection with this sort of scheme.

Most builders believe in selling or attempting to sell Diesel engines where they are well fitted for the conditions involved. Usually the cost of power generation is the outstanding point of consideration, and where it is, the usual practice is to abandon the prospect if a substantial saving is not possible. In towns and cities the Diesel-engine salesman finds a lucrative field where non-condensing steam plants are still in use, where old-type surface-ignition engines have become obsolete, and of course, as was previously stated, some of them start a campaign for a municipal plant where a town served by a public utility has poor service and high rates or both.

### Author's Closure

As Mr. Allen so ably puts it, power production is a business in itself, but it cannot expect to fulfil its highest obligation as a business until it supplies electrical energy to industrial and residence users at a rate which does not allow for tremendously expanded capital charges and an unreasonable margin of profit.

Mr. Thuerk is quite right in pointing out that there will always be competition between the two industries, especially so far as the smaller industrial and municipal plants are concerned.

Mr. Beck has pointed out a situation which has very largely been forced on the builders of medium-sized engines by the uncomprising attitude of the utility companies; although there is considerable to be said on both sides of this story, and obviously it is preferable if both industries can confine their activities to their respective fields.

Mr. Dow's remarks allude to a withholding of statistical data

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[8] General Manager, *Oil Engine Power*, New York.

[9] Sales Engineer, Busch-Sulzer Bros.-Diesel Engine Co., Kansas City, Mo. Assoc-Mem. A.S.M.E.

which will be eliminated when the utilities make "public service" a real expression instead of a catch phrase. If the utility company has a sound and reasonable rate structure, there can be no valid reason for withholding data on power costs.

However, there are conditions of technical ignorance, biased sales policies, and misrepresentation of various types of power costs which can be constructively eliminated.

In closing, it is probably well to recall that the author's paper is based on an inquiry into the problem discussed which has extended over a period of about two years, during which the views of most of the important Diesel and public-utility executives have been obtained. A survey of technical schools has also been made in order to get at the facts regarding the Diesel training of American engineers.

The entire move for cooperation so far as is possible at this time is not based on any desire to gloss over the situation, but is primarily an attempt to infuse a spirit of "good business" and all that it implies.

# One Example of Centrifugal Pumps for Petroleum Transportation

By FLOYD E. WARTERFIELD, JR.,[1] MUSKOGEE, OKLA.

*This paper deals with the problems involved in one specific installation of motor-driven centrifugal pumps for pipe-line work. The author describes conditions prior to the installation, and gives the reasons for the selection of centrifugal pumping units, as well as actual construction and operating costs so far as possible. He also discusses the effect that the experience gained from the installation described may have on the future use of centrifugal pumps in petroleum transportation.*

RECENTLY there has been much agitation as to the relative merits of pumping equipment. A great many comparisons have been made upon purely assumed conditions. It is unfortunate that there are so few actual data available, upon which to base a direct comparison between different classes of equipment, or between different equipments of the same class. The elements entering into pipe-line "cost analysis" are, for the most part, hard to determine; and when once determined, hard to evaluate correctly. Because of this difficulty, some one or more of the component parts are only roughly approximated or else omitted entirely. Every pipe line or station presents its own particular set of problems, and it is wholly unfair to assume that whatever may serve in one case would work equally well in any other. Before a true comparison can be made between any two stations, the whole story should be told, and the existing conditions in each made absolutely plain.

In view of the foregoing statements, this paper will confine itself largely to the problems involved in one specific installation of motor-driven centrifugal pumps for pipe-line work. It has for its purpose, first, the presenting of the conditions prior to the installation; the reasons for the selection of the centrifugal units; and so far as possible, actual construction and operating costs; and second, the effect that the experience gained from this one installation may have upon the future use of centrifugal pumps in petroleum transportation.

The data and information have been furnished through the courtesy of the Oklahoma Pipe Line Company, and the installation referred to is the one known as their Henryetta Station (Fig. 1).

Initially, a 10-in. line had been built between their Cromwell and Council Hill Stations, to provide an outlet for a portion of the oil produced in the Seminole Area. The line was designed to handle 32,000 bbl. of oil per day at 480 lb. pressure. The gravity varied from 35 to 40 deg. A.P.I. and had an average viscosity of about 48 sec. Saybolt Universal at 60 deg. fahr. Some concern was felt as to whether there would ever be sufficient production for the line to operate at its maximum capacity. But, as frequently happens in pipe-line work, the line was hardly completed before it was found necessary to effect an immediate increase in the delivery to Council Hill.

The guide chart shown in Fig. 2 is introduced for the purpose of showing one method that may be employed for the rational selection of pumping equipment but will be discussed only so far as it applies to the equipment selected at Henryetta Station.

Production from a new field is almost invariably well in advance of all storage and pipe-line facilities. Seminole was certainly no exception. As is always the case in caring for a sudden increase in output, the element of time becomes the one item of paramount importance.

To attempt to determine, even approximately, the maximum production of a field, the time required for it to reach a settled figure, or even what this amount would be, is most certainly a hazardous undertaking for any one. However, it was generally believed that the added capacity, so far as this case was concerned, represented a peak load that would only be handled for a maximum of six months. At the end of this time the load would have fallen to the original value of from 30,000 to 32,000 bbl. a day.

It is customary to compare equipment, and in some instances (where ample time will permit) to select it on the basis of the "unit cost per barrel of oil pumped." Even under ordinary conditions "time of operation" is hard to determine. "Time of operation" refers to the length of time the equipment shall operate, and is a very important item in the unit cost figure. Under the stress of "do it now" it seldom, if ever, receives the consideration that it should. It is generally the case that comparative analyses, and more especially where the time for the increase is short, are forced to neglect "fixed charges" and the equipment is selected on the basis of the "time required for delivery." Unit-cost comparisons are investigated at some future date.

There was adequate pump capacity at Cromwell Station for the proposed increase and the problem was to find the quickest way in which the delivery could be made to Council Hill. It was a case of either looping the line or constructing an intermediate booster station. No line pipe was available, and even if there had been, with an adequate amount of time in which to lay it, the expenditure of $528,000 would not have been justified, for the short time it would be used. In order to effect the ultimate increase that has been realized, approximately 37.6 miles of 10-in. pipe, laid from Council Hill and parallel to the old line, would have been required. Computations for a booster station placed it at a point quite close to an existing high line, and electric power could be obtained quickly and easily.

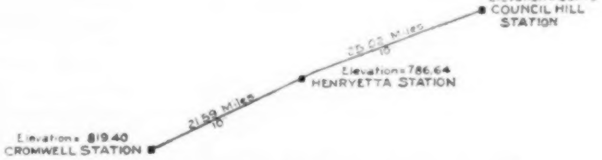



FIG. 1 LOCATION OF HENRYETTA PUMPING STATION OF OKLAHOMA PIPE LINE CO.

Immediate delivery could be made on motor-driven centrifugal units, and as a whole conditions seemed to be ideal for their use. It was realized that the operating cost would be high, but with due consideration for the time saved and the low fixed charges, it was thought that the high rate could be profitably paid for the short time the units would be in service.

Accordingly there were installed two automatic compensator-controlled 300-hp. 440-volt General Electric induction motors, driving two Byron-Jackson 6 × 17½ four-stage centrifugal pumps arranged in series and running at a full-load speed of 1750

[1] Oklahoma Pipe Line Company.

Presented at a meeting of the Mid-Continent Section of the A.S.M.E., Tulsa, Okla., December 1, 1927.

r.p.m. Following is a summary of the installed cost of the present completed station. As will be explained later, certain changes were made in the motors. The cost given does not include the expense of making these changes but is given as though the present equipment had been initially installed.

| | |
|---|---|
| 1 Pump-house building and incidental construction, i.e., small storehouse, roads, walks, grading, fencing, etc. . . | $ 3,500 |
| 2 Pumping equipment to include pumps, motors, switchboards, foundations, wire, and miscellaneous . . . . . . . . . | 16,000 |
| 3 Other station equipment, to include 5000-bbl. surge tank, gages, pipe, gates, and miscellaneous fitting and connection work . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | 9,000 |
| Total . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | $28,500 |

and keeping the station in an operating condition. When it was found that the pumps would deliver this quantity of oil, and that the line capacity was adequate, it was thought advisable to correct for the overload on the 600 hp. of motors by installing two of 400 hp. each and operating at 2300 volts.

The increased delivery is explained by the fact that the weather was warm and the oil run fresh from the field at a temperature of 75 deg. fahr. On test the oil showed an average gravity of 38 deg. and a S.U. time of 46 sec. In addition there was actually 155 ft. of fall between Henryetta and Cromwell that was only approximated in the original calculations. In order to protect the motors as much as possible the station was run with a wide-open header gate during the cooler hours of the day, and under

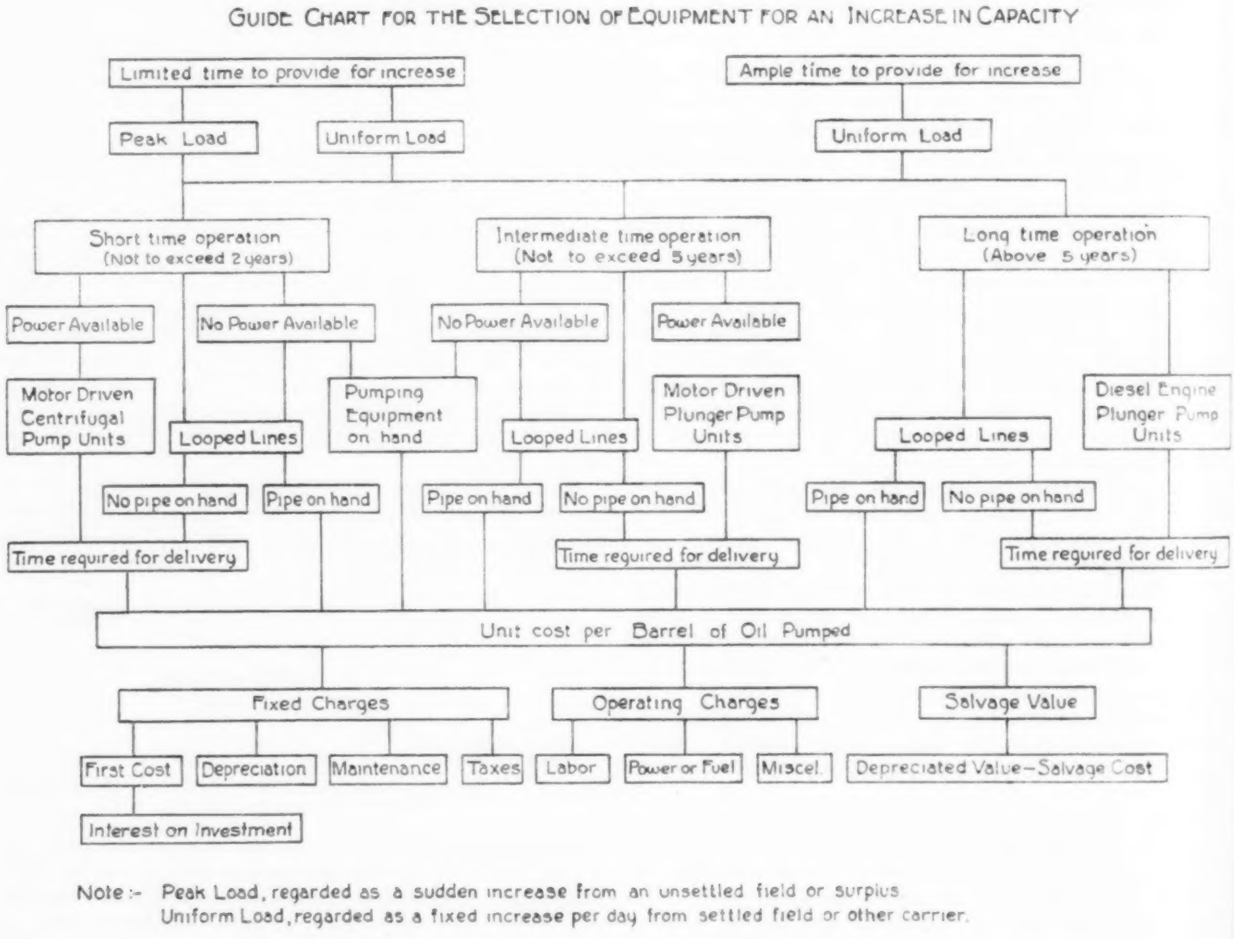



FIG. 2 GUIDE CHART FOR USE IN SELECTION OF PUMPING EQUIPMENT FOR AN INCREASE IN CAPACITY

Local construction conditions for this station were far above the average. If an estimate should be required for a similar installation remotely located and built under adverse conditions a figure of $30,000 would be approximately correct.

The installation was designed for the adverse operation usually experienced in winter pumping and was to deliver 44,000 bbl. of 38-deg. A.P.I., 75 sec. Saybolt Universal oil, at a pressure of 580 lb. Much satisfaction was experienced when the station was started the latter part of April, and it was found that the capacity exceeded that calculated for the assumed conditions. The increased delivery was very much needed, yet it could only be realized at the expense of a very severe overload on the motors. This caused no small amount of trouble in maintaining

this condition delivered around 50,000 bbl. per day at a line pressure of 535 lb. For the remainder of the time the gate was pinched down in order to raise the head and decrease the load on the motors, with a consequent reduction in delivery.

At the present time the oil has a line temperature of about 60 deg. fahr., with a S.U. viscosity of 52 sec. When the header gate is wide open, the delivery is around 51,500 bbl. per day at 580 lb., and no troublesome temperature overloads have developed such as were experienced with the 300-hp. motors.

The following is the result of a brief test made by representatives of the Oklahoma Pipe Line Company and the Oklahoma Gas and Electric Company to determine the approximate mechanical efficiency of the pumps:

TEST OF OKLAHOMA LINE COMPANY'S HENRYETTA STATION, MAY 31, 1927

*Equipment*

Two 300-hp. motors, 1750 r.p.m., 3-phase, 6-cycle, 440-volt
Two 6 × 17½ 4-stage Byron-Jackson pumps arranged in series

*Electrical Data*

SUBSTATION TESTS, 2300-VOLT SIDE OF THREE 2300/440, 200-KVA. TRANSFORMERS

| Kw. | R a/c Kva. | Kva. | Power factor | Transformer losses |
|---|---|---|---|---|
| 592 | 296 | 662 | 89.5 | 22 |

| | Avg. amp. per phase | Avg. volts per phase | Power factor | Kw. input | Hp. input | 92 per cent motor effy., b.hp. |
|---|---|---|---|---|---|---|
| High-duty pump.... | 420 | 448 | 89.5 | 290 | 388 | 357 |
| Low-duty pump.... | 405 | 448 | 89.5 | 280 | 375 | 345 |
| | | | | 570 | 763 | 702 |

*Oil-Pipe-Line Data*

| Line pressure Suction | Discharge | Bbl. per hr. 12 M. to 1 P.M | Viscosity S. U. deg. | Temp. oil, deg. fahr. | Hydraulic hp. |
|---|---|---|---|---|---|
| 12 | 555 | 2057 | 46 | 75 | 466 |

*Efficiency of pump* $\frac{466}{702} \times 100 = 66.2$ per cent

NOTE: A 5000-lb. working tank was installed and the suction pressure of 12 lb. was due to the height of the oil above the level of the pumps at this period. The header gate was pinched down and the pressure given is between the discharge of the high-duty pump and the header gate.

The actual money expended for operation during the months of May, June, July, and August is as follows:

| | | |
|---|---|---|
| 1 Maintenance: | | |
| a Material for repairs............ | $ 99.34 | |
| b Labor for repairs............... | 613.49 | $ 712.83 |
| 2 Transportation Operation: | | |
| a Station, labor, regular.......... | 3,307.42 | |
| b Casual labor and misc. (i.e. waste, lamps, brooms, etc.)........... | 470.12 | |
| c Lubricating oil................. | 50.53 | |
| d Power (1.03 cent per kw-hr.).... | 14,984.44 | 18,812.51 |
| Total........................ | | $19,525.34 |

Total barrels of oil pumped during period.............5,464,002.2
Total energy used, kw-hr..............................1,454,800
Average number of barrels pumped per kilowatt-hour.........3.75
Operation and maintenance cost alone, per bbl., cents.......0.3575

With the foregoing figures as a basis, maintenance is 3.65 per cent of the total transportation cost and is at the rate of 7.8 per cent per year on the present investment of $27,500. This rate of 7.8 per cent is not a true figure; it should be slightly higher due to the fact that the present investment is greater than it was at the time the maintenance figures were taken. It must be remembered that the maintenance cost of $712.83 applies to a time when the station was being placed in operation and that many things were done that would be avoided in the future. Considering the heavy overload that was placed on the motors, it is not unreasonable to assume that the operation was abnormal in every particular. The present 400-hp. motors have not been in operation long enough for a true figure to be determined, but indications are that it will not exceed 3 per cent of the total cost as a yearly maintenance cost.

In order to arrive at an exact cost per barrel of oil pumped it is necessary to take into account the item of fixed charges. For this purpose, the useful life of the station is assumed to be 20 years and the functional depreciation to be taken care of by setting up a 4 per cent sinking fund to provide for replacement. Interest on the total investment is at the rate of 6 per cent, and taxes 3 per cent.

PUMPING COST

(Four months operation)

| | | |
|---|---|---|
| *Fixed Charges* | | |
| Interest on investment.................. | $550.00 | |
| Depreciation............................ | 307.80 | |
| Maintenance............................. | 712.83 | |
| Taxes................................... | 275.00 | |
| | | $ 1,845.63 |
| *Operating Charges* | | |
| Labor, power, and miscellaneous................... | | $18,812.51 |
| Total..................................... | | $20,658.14 |
| Unit cost per barrel of oil pumped, cents.................. | | 0.3780 |

A comparison between the actual cost at Henryetta and an estimated cost for a motor-driven plunger-pump station of about the same capacity may not be entirely correct, but if all the items are considered some idea of the respective operating costs can be obtained.

50,000-BBL. TWO-UNIT BOOSTER STATION WITH MOTOR-DRIVEN PLUNGER-PUMP UNITS

| | |
|---|---|
| 1 Pump-house building and incidental construction....... | $12,000 |
| 2 Pumping equipment, to include two 300-hp. motors direct connected to two 25,000-bbl. triplex plunger pumps, and miscellaneous........................ | 50,000 |
| 3 Other station equipment, to include working tank and all incidentals....................................... | 13,000 |
| Total........................................ | $75,000 |

The station is assumed to deliver an average hourly amount of 2085 bbl. of 37-deg. A.P.I., 52 sec. S.U. oil through 25 miles of single 10-in. line at a pressure of 580 lb. Efficiency of the pumps, 85 per cent, and of the motors, 93 per cent. The useful life is assumed to be 20 years, with depreciation taken care of by a 4 per cent sinking fund to provide for replacement; maintenance and taxes taken at 3 per cent and interest on the total investment at 6 per cent. Computations based on 730 hours' operation at a flat rate for power of 1.03 cent per kw-hr.

| | | |
|---|---|---|
| *Fixed Charges* | | |
| Interest on investment.................. | $ 375.00 | |
| Depreciation............................ | 209.87 | |
| Maintenance............................. | 187.50 | |
| Taxes................................... | 187.50 | |
| | | $ 959.87 |
| *Operating Charges* | | |
| Regular station labor..................... | $ 525.00 | |
| Incidental labor, lubricating oil and miscellaneous material for operation....... | 300.00 | |
| Power.................................. | 3,500.09 | |
| | | $4,325.09 |
| Total........................................ | | $5,284.96 |
| Total barrels of oil pumped in 730 hours............... | | $1,522,050 |
| Unit cost per barrel of oil pumped, cents.................. | | 0.3471 |

This would indicate that the plunger-pump station would operate 0.0309 cent, or 8 per cent per barrel cheaper than the centrifugal units. However, for short-time operation, if the centrifugal units could be delivered and installed quicker, this difference can be disregarded.

That a working tank is unnecessary is a point frequently advanced in favor of the centrifugal pump. There are instances wherein this is true, but the unqualified statement will not hold for all cases. For example, the pumps at Cromwell Station were all of the plunger type, and in case of an enforced and unforeseen shutdown at Henryetta, immediate and very destructive

pressures would be built along the line. To safeguard against this emergency, relief valves had to be placed on the discharge lines from the pumps at Cromwell. There is no question that relief valves do afford some measure of protection, but by no means should they be regarded as positive insurance against accident. Further difficulty was experienced at Henryetta due to the low-duty pump pulling a vacuum and hence working at a decided disadvantage. A surge tank was the only logical solution to the troubles, and in addition to providing adequate safety, insured a well-filled pump. Positive local control has everything in its favor, and present experience indicates that a working tank will merit the added expense and should most certainly be installed.

If conditions in the future should be similar to those described for Henryetta Station, there is no doubt that a centrifugal installation would be made. In addition to some of its other advantages, the series arrangement of pumps is very desirable. When their main-line service is terminated they may be used as individual units on local-station work where only a temporary installation is required. Not only are the units compact and comparatively light, and hence can be transported easily, but they require a minimum foundation and housing space and can be installed more quickly than any other unit of even greater capacity.

A serious drawback to the centrifugal pump, and especially with small quantities at high heads, is its low mechanical efficiency. When coupled with an electric motor as a prime mover, the rate that can be paid for power must necessarily be as low as possible. Because of this low efficiency, the power companies should not be expected to compensate for it by furnishing power at a loss. Neither should the power companies penalize the pipe lines because they use the electric motor—in itself a remarkably efficient piece of equipment. It is almost time for the rate makers to adjust their demand and standby charges to fit true conditions. Apparently sufficient consideration has not been given to the fact that pipe-line work is the exact opposite of an industry. The pipe line in general begins with a peak and grades downward; the industry usually starts with a minimum and works toward the peak. It is doubtful if one rate can ever be conceived that can apply equally to both classes of loading. Centrifugal- as well as plunger-pump manufacturers naturally desire the best possible efficiencies for their products, and competition will keep them striving for improvement. Whether they succeed or fail, before the electric motor can retain its rightful place in oil-field work some change must be made in power rates. It is realized that the whole method is relatively new and that present rates may be the nature of an experiment; yet unless there is some revision, power companies are in danger of finding themselves with ample equipment on their hands for service—and no customers.

Pipe lines have been constructed wherein all stations used motor-driven centrifugal pumps entirely, but it is unlikely that this practice will meet with much favor in the Mid-Continent Field when the rates that must be paid for power are seriously considered.

The data that have been presented for this one installation should not be used as a criterion for the acceptance or rejection of the centrifugal unit. Although not entirely defined, the centrifugal pump does have a real place in petroleum transportation, and its use under certain conditions will not only be continued but increased. However, it must be remembered that each installation is to stand on its own feet, and that the selection of any pumping equipment must be made on the basis of existing circumstances.

# Progress in the Petroleum Industry

## Contributed by the Petroleum Division

Executive Committee: H. R. Pierce, *Chairman*, W. G. Heltzel, *Vice-Chairman*, P. L. Guarin, *Secretary*, Walter Samans, T. H. Kerr, and C. F. Braun

PROGRESS in the petroleum industry has its many ramifications, and the Petroleum Division in planning its review of this year's progress decided to subdivide its field and to request from a few prominent engineers a report on progress in their respective fields. The reports on these subdivisions contain valuable material that deserves the adequate treatment given by the authors, particularly because of the novelty of the matter treated and its paramount importance to several great branches of mechanical engineering. In view of this the Petroleum Division presents its Progress Report for 1927 as a symposium of reports of these subdivisions.

W. G. Heltzel, *Vice-Chairman.*

## Progress in the Production of Oil

By HOMER R. PIERCE

THE producing formations have been getting deeper and as a consequence drilling and development methods have had to change very rapidly during the past year. The deeper sands, having a higher gas and hydrostatic pressure, deliver their oil to the drill hole at a much higher rate than shallower sands, and due to the greater quantity of energy per barrel of sand-stored oil, there is a greater percentage of the stored oil recovered and at a much more rapid rate of production.

Due to the nature of this stored energy, the drainage area of a well is enlarged so that the number of wells per unit area can be cut down, thereby reducing expense in drilling; but due to the same condition the drainage to offset production is greater, and lack of adequate line protection results in loss of one's potential production to a neighbor.

Due to the greater stored energy even with the wider spacing of wells, the oil enters the drill hole at a rapid rate, and its removal from the well at a higher rate becomes more and more of a problem. The old equipment used to remove oil entering from shallower sands fails to keep the column of oil down, and consequently the back pressure on the sand low, so that one's oil seeks his neighbor's outlet when and if the latter is holding a lower producing pressure on his sand.

To meet this condition there have been numerous long-stroke high-speed pumps developed and new kinds of swabs and bailing methods tried, but due to the extreme depth of the wells, crooked-hole conditions, and the large quantity of fluid to be lifted, as well as sanding and cup trouble caused by the high rate of flow through the sand, the above-mentioned methods have proved fairly expensive in the upkeep of physical equipment, and absolutely prohibitive in waste of time where offset production could be produced more rapidly, or continuously.

### Air-Lift Method Best for Large Quantities of Oil

Consequently, the most successful and cheapest method of lifting large quantities of oil from great depth and under floating-sand conditions is by what is called the air-lift method. In some cases where the compressor equipment is installed and the wells properly tubed to give the maximum efficiency, production can be carried to its economic limit by this method of lifting, but in other cases it is necessary after the pressure in the sand has been drained to revert to the pump as a means of more completely depleting the sand.

These are problems which must be solved for each district, pool, or property, and in most cases for each well.

Some companies have realized that these problems are worthy of trained mechanical engineers, and are getting results comparable with their ability to pick engineers for the work and their ability to act on or judge the value of reports or advice of the engineers they employ.

### Pool Production or Control Necessary

The high cost of drilling wells and keeping up offset production under the present competitive conditions, together with the resultant overproduction and reduced price, have made the substantial thinking heads of the oil industry realize that pool or unit operation or some method of control is necessary. This will in the near future allow of pool operation, which in turn will demand more engineering applied to production. That is, the pool to be operated will be analyzed and drilled with a view to the conservation of its natural energy, and with a future view of restoring energy to the sand at such a time and in such a manner that the greatest ultimate production will be had at a minimum expense per barrel produced.

This will mean that from the beginning the wells will be flowed in the most efficient manner; and, as it is necessary, the gas will be returned to the rock and used as an expulsion and lifting agent, and differentials across the sand and from the sand to the flow tank or gasoline plant will be regulated so that the maximum energy in the gas will be utilized.

Hard-headed business men in the oil business are fast becoming disgusted with the wholesale waste occasioned by highly competitive drilling and production methods, and once started on the warpath they will devise some means of improving conditions, because these men are today where they are, due to their ability to handle hopeless situations in a speedy and profitable manner.

When this time comes, as it soon will, the engineers are going to have more problems put up to them than they can handle. Therefore it behooves them to be preparing now for their future task. The ability to look ahead and prepare for the future needs is just as much engineering as the solving of the problems coming up from day to day.

The problems of producing large quantities of oil from deeper horizons do not confine themselves only to the designing of flow tubings and proper ratios of pressures, but necessitate working out better joints for the various ratios of tubings and the many strength-of-material problems entering into deep-well pumping.

### Corrosion

Corrosion alone presents a wide field for investigation. Corrosion problems increase when handling deeper and more concentrated waters. This is especially true if air is used as a lifting medium.

Some of the deeper pools, which as explained deliver oil at a higher rate due to the excessive amount of energy stored in them, contain sulphur and other constituents which corrode metal very rapidly, and due to the fact that it is necessary to

remove this oil in order to keep pace with the production of neighboring wells as explained above, corrosion problems are in direct proportion to the rate of production.

# Development of Mechanical Equipment for Petroleum Production

By HOLLIS P. PORTER

THE progress of engineering in the petroleum industry has been very satisfactory during the past year. The greatest degree of improvement has been in the development of mechanical equipment, its application to the production of petroleum, and the handling and storage in field operations.

The air-gas lift has been applied very extensively to aid in flowing wells. This has been the cause of several new designs of semi-portable compressors driven by either multi-cylinder engines or electric motors. There are large, slow-speed units direct connected, being used for more permanent service.

### Problems Presented by Deeper Drilling

Deep drilling has caused many problems to be presented to the mechanical engineer. In the Gulf Coast region at Spindle Top and other fields, deeper wells are being drilled. In California, an editorial in the September number of the *Oil Field Engineer* shows that in a list of some 391 wildcat wells drilled in 1925 and 1926 the depths ranged as follows: 98 wells between 4000 and 5000 ft., 71 between 5000 and 6000 ft., 21 wells over 6000 ft., and one well recorded at a depth of 7221 ft.

In the Mid-Continent and West Texas fields there is a great amount of deeper drilling between 4000 and 5000 ft.

As a result of deeper drilling, heavier machinery is being used. Batteries of three boilers to a drilling well, each boiler having a capacity of 100 hp. and a pressure of 200 lb., is now the practice. This can be compared with the use of two 45-hp. boilers for 125 lb. pressure, which was considered sufficient in most territories a few years ago.

The mechanical engineer is being called upon to not only design better and heavier machinery, but also to direct the way to better methods and more economic practices. The use of compound slush pumps which use 50 lb. of steam per hp-hr. compared to the present simple pump using 100 lb. of steam per hp-hr. will soon be common practice, but this must be carried farther by the adoption of a type of simple condenser, if steam is to be used for drilling. Electricity will replace steam where electricity is available for drilling, and gas engines will be used more for drilling as time goes on. These improvements are now being adopted rapidly, and the mechanical engineer is called upon to apply methods of economy to the production of oil the same as he has in the past in other lines of industry.

The development and operation work of the production departments have, in the past two years, added to the organization ten engineers and technical men where there was but one before.

# Progress in Rig and Field Equipment

By GLENVER McCONNELL

THE percentage of all wells drilled to depths of 4000 and 5000 ft. has increased very greatly during the past year. This has been accomplished by the use of more powerful machinery, a higher quality of tubular goods, and better selection of wire rope and transmission equipment. Aside from this, little effort has been made to introduce new equipment that is not built according to standard designs. Very little effort has been made to reduce the power costs, although there is some tendency to adopt high-speed bearings and to improve the lubricating systems.

Much improvement has taken place in equipment designed for greater power and speed in rig hoisting requirements. Manganese-steel sheaves, larger-diameter hoisting drums, stronger steel derricks and crown blocks, and many devices for better rope service have come into use. Now efforts are being extended toward improving belting conditions for heavy drilling and pumping machinery, and more attention is given to safety requirements. The industry has practically adopted the use of steel derricks, and it is predicted that the use of timber foundations will soon be a thing of the past. The influence of the A.P.I. program for the purpose of standardizing equipment in the oil fields has been a great aid and is increasing in its importance. Pipe and tool joints are being obtained which are made according to A.P.I. standards. The result of this is that a more uniform and safe product is in general use. If the A.P.I. committees do not accomplish anything more than to bring to light the glaring defects in equipment that has hitherto been considered satisfactory, the good that they will accomplish will be invaluable. As the engineers continue to study the ways and means for standardizing on such articles of equipment as belting, wire lines, manila cordage, pump specifications, and numerous other items, they are frequently forced to admit that heretofore too little was known of the mechanical requirements of drilling and pumping equipment. The choice of power-transmission equipment becomes more difficult when it is considered that the selection of electricity, steam, or internal-combustion engines is generally governed by the means worked out for satisfying drilling and pumping requirements. Two-speed-reduction machinery is being introduced satisfactorily in some districts for pumping, but it cannot be said that for permanent equipment or for standard purposes there is sufficient accomplishment for general adoption.

Requirements for drilling machinery less expensive to operate will necessitate more consideration on the part of oil-company executives to appreciate complicated designs and arrangements that are carefully engineered. Then, too, a system of instruction will be needed for all field men in the proper care and use of equipment. Many executives are loath to consider this, but it is generally realized by engineers that a great saving in operating costs cannot be expected unless basic changes are made in much of the rig machinery now more or less standard. Haste is too much the governing factor. Production at any cost rules the instinct of a successful operator. With this condition to meet, a larger and larger number of able men confine their efforts to improving the drilling tools, the well-head control devices, prime movers, rotarys, and a multitude of miscellaneous items from burners to sand pumps. In fact, it is difficult to keep a well-trained mechanical engineer in the field long enough for him to learn what basic changes are needed and to fit himself for the task of developing a more efficient system of drilling and pumping machinery in the face of more remunerative openings in the specialty field. But the industry offers a promising future to men who will hasten the time when it can be said that highly efficient means of drilling and producing oil and gas have been accomplished.

It is predicted that within the next twelve to eighteen months when the overproduction now prevalent has ceased to exist, a great awakening to the needs of lower operating costs will be followed by such improvements in mechanical engineering in the oil fields that the gradual progress of the past will be looked upon as insignificant. The cry for competent engineers is beginning to be heard on every side. Their work in the field operating division of the industry will revolutionize present conditions.

# Progress of the Natural-Gasoline Industry for 1926-1927

By H. B. BERNARD

THE natural-gasoline industry during the past twelve months has had a tremendous impetus due to the development of new fields in California, in the Panhandle of Texas, and in Seminole and Pottawatomie Counties, Oklahoma.

The problems presented in new construction in California did not entail any novel features or anything of special interest.

In the Panhandle Field of Texas the high content of hydrogen sulphide in the gas processed in gasoline plants called for experimentation with and design of equipment to withstand the extremely corrosive action of the gas. To date the problems have not been completely solved, but great progress has been made by engineers and chemists of the industry. The gasoline produced from the gas necessitated the design of special equipment and the introduction of new processes for its treatment.

Under a recent arrangement between several operating companies in the Panhandle Field the natural-gasoline and the pipeline departments of the industry have cooperated to develop more economical methods for the transportation of crude oil admixed with natural gasoline. At this time the experiment is of short standing and consequently no results are available.

## Twofold Use of Air or Gas Lift

In Seminole and Pottawatomie Counties, Oklahoma, wherein is located what is known as the greater Seminole Field consisting of the Searight, Seminole, Bowlegs, Little River, and Earlsboro pools, the principal problem presented has been the use of the air or gas lift used, first, as a means used solely for producing oil, and second as a means for producing oil and extracting gasoline with the same equipment. As the equipment used for flowing wells and producing gasoline at the same time is practically identical with the equipment utilized for the more limited application, any summary may be confined to the twofold system.

Prior to the application of the gas lift to the production of crude petroleum, natural-gasoline plants of the absorption type had practically supplanted plants of the compression type due to the economic conditions involved and not due to the greater efficiency of the former, which is the common impression. In 1926 one of the major oil companies in the Browning Pool near Madison, Kan., constructed a compression gasoline plant built for the primary purpose of extracting gasoline but with two secondary objects in view, the first of which was to put gas pressure back on the sand, and the second to produce oil from the relatively shallow wells (about 2200 ft. deep) with the gas lift. This plant has been very successful and was the forerunner of the double application of compression gasoline plants.

Early in the history of the Seminole Field the first gasoline plants in that area were conceived (about August-September, 1926). These plants were universally of the absorption type, and made no provision for the production of high-pressure gas for flowing purposes. About sixty days later when several high-pressure compression plants using both air and gas were put in service, it was found that where gas was the medium compressed, gasoline was extracted, but as no final coolers were installed on the second stage, the gasoline production was very small. A short time later it became a more or less general practice to install an absorption-type unit on the discharge of the low-stage compressors to extract the gasoline, and this method is in more or less universal use in those plants constructed late in 1926 and early in 1927.

Considering that the condensing and cooling of a given amount of gasoline over a definite temperature range requires a given amount of condenser surface and with the view of eliminating absorbers, stills, and the numerous auxiliaries used in connection therewith, one of the major oil companies in March, 1927, put in operation a gasoline plant, designed not only to efficiently extract gasoline under compression methods but to furnish high-pressure gas for producing crude petroleum by the gas lift. Shortly thereafter this plant was put in successful operation, and it has set a model type of construction and operation which will replace the high-compression type of plant utilizing absorption equipment for gasoline extraction. One of the principal problems presented in the construction of the two-purpose compression plant was the design of a system of controls to enable the operation of each individual well under the most favorable conditions and to permit the "kicking off" of any well or wells without interference with other operations. This system was fully developed in July of 1927, and while it is undoubtedly capable of improvement, as the question now stands it is eminently satisfactory in operation both from the engineering and operating standpoints.

To permit the operation at normal pressures (250–300 lb. per sq. in.) for gas lift in the Seminole Field, and to provide for the same units to operate at 650 lb. per sq. in. for "kicking off" the wells, required the design of special cylinders, and the initial development of this equipment was found satisfactory. As the machinery is designed to operate fully loaded at the lower pressures, throttling devices on the suction for high-pressure operation have been resorted to.

The application of the principle of compression for a twofold purpose has resulted not only in economy of operation but has permitted the construction of large central plants as opposed to the construction of a number of smaller plants, with a corresponding further increase in operating efficiency and economy.

## Use of Superheated Steam for Power and Process Requirements

During the past year superheated steam was used for the first time in natural-gasoline plants for power and process requirements. This development is too recent to permit reporting on its results. The use of marine-type boilers in three plants of one large operating company during the past year has shown splendid results, in which a high steaming rate has been combined with low construction, operating, and maintenance costs. The high furnace temperatures developed in this type of equipment, however, required a careful selection of refractory equipment, but this feature appears to have been successfully worked out.

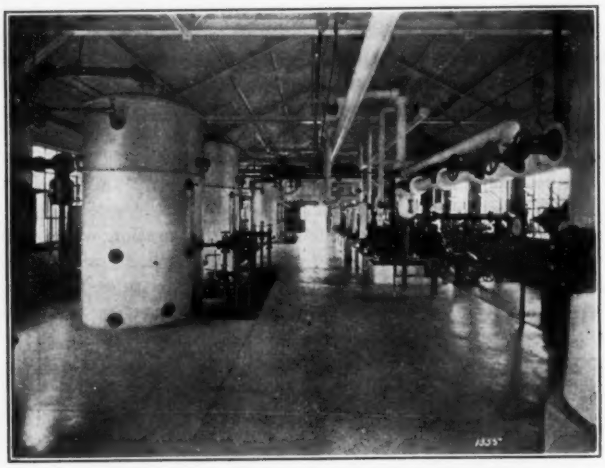
The use of base-exchange and lime-soda water-treating systems has become more general than in previous periods, as has the application of automatic controls not only in the power plant but in the process equipment as well.

In cases where economic conditions have permitted, the use of electricity for power purposes has had considerable impetus, but it is not promised that that medium will be general as local conditions must be considered.

## Gas Injection on Two-Cycle Engines

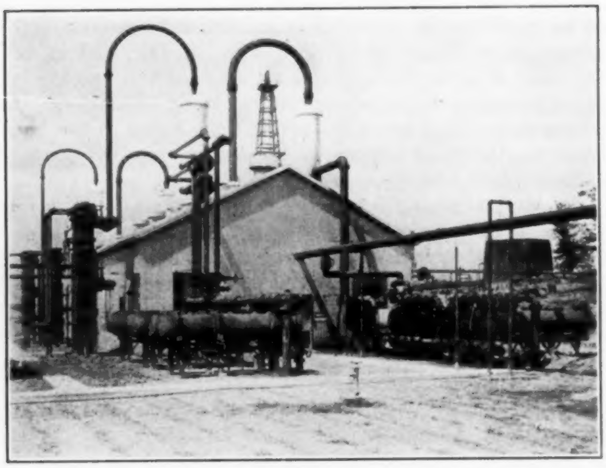
The gasoline industry is the first to apply the more recent development in internal-combustion engineering. This is the application of gas injection on two-cycle units, which makes them operate on the Diesel cycle rather than on the Otto cycle. Preliminary results point to economy on two-cycle units comparable with that expected in four-cycle operation.

The construction of large units has called forth great improvement in the design of cooling towers, which appear to have largely supplanted spray ponds. While atmospheric-type coils continue to be used for cooling and condensing service, the shell-and-tube-

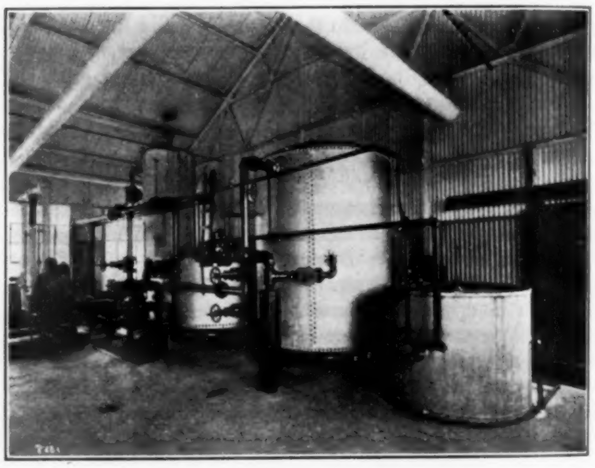


Control Building, Natural-Gasoline Plant

Engine Room of Natural-Gasoline Plant Containing Thirty-Two 180-Hp. Compressing Units



Exterior View of Control Building Above



Zeolite Treating System for Handling Water of High Turbidity

General View of a Natural-Gasoline Plant in the Seminole Field

type design is rapidly becoming preëminent. Certain advantages of the atmospheric coil and recent improvements in its design assure its continued use, and it is not expected that it will be entirely supplanted by shell-and-tube-type equipment when proper consideration is given to the local conditions surrounding individual installations.

It may be said in conclusion that the past year has been one of great progress in the gasoline industry, not only through the increased scale of its operations, but because of the greater attention given to detail of design and utilization of equipment. During the past year the three largest gasoline plants in the world were constructed, one in California and two in Seminole County, Oklahoma. The lowest natural-gasoline prices in history have demanded more efficient conception, design, and operation in all branches of the petroleum industry, and in the advance and application of engineering knowledge the natural-gasoline branch of that industry has had its due share.

# Development of Transportation of Crude Oil in 1927

By B. P. Sibole

ON THE rails, in the water, on the highways, and through the air, "Speed" has been and is the slogan. In marked contrast to this, "Conservation" has been the keynote in the transportation of crude oil, especially by pipe line. This is particularly noteworthy, because an occasional suspicion of waste has been directed to this branch of the oil industry.

All crude oil is gathered from the wells by pipe lines, and while a small portion is carried to delivery or tidewater by tank cars, most of it goes on to such delivery by pipe line. Over two million barrels (or 300,000 tons) are handled every day by pipe line. Much of it is transported in this way for hundreds of miles, and yet all of this enormous movement is carried on safely and with a very high degree of economy.

Pipe lines have been extended into new fields, but the outstanding tendency in 1927 has been the development of still further economy and measures of conservation both on new lines and on old lines already in operation. This development has been marked by conservation of oil and equipment, and economy of movement.

## Conservation of Oil

Long ago the pipe lines developed ways and means which have practically eliminated loss by leaks and breaks. In recent years the losses due to the fugitive vapors escaping have been the subject of constant attack. The floating roof continues to achieve excellent results in eliminating vapor loss from working tanks, and this year witnesses the appearance of the breather roof, which is an ordinary steel roof welded to the shell and so designed that it will rise and fall (as a diaphragm does under varying pressures) to take care of an ordinary change in volume of a tank practically full of crude oil without the safety relief valves being called on to operate. This type is for storage tanks.

The expensive lessons taught when lightning ignited large concrete storage reservoirs in California last year have resulted in the development of spires and aerials for the protection of such storage. The splendid record of comparative immunity from fire held by properly vented steel-roof storage tanks has resulted in a continuation of the tendency to build this sort of tank and replace wood roofs with steel.

## Conservation of Equipment

No radical change or improvement in materials has been made. All of these continue to suffer from the ravages of corrosion. The enormous depreciation of pipe in the ground has continued to stimulate the development of protective coating for steel pipe, which material is still the almost universal standard for pipe lines. It was just two years ago that a type of pipe-cleaning machine was brought out which has in the last year been put into very wide use. By a device of this kind, old lines can, after they are uncovered and raised, be quite effectively cleaned, permitting the outside pipe surface to receive a coating of asphalt, tar, or other protective materials. Recently such a machine has been used on new pipe as received from the mills, with the apparent object of removing the mill scale and getting a fairly clean and new metallic surface to which to apply protective coating.

While heretofore most of the corrosion of pipe-line equipment has been on surfaces not in contact with crude oil, such as the outside of pipe lines, the outside of tanks, and the inside of steel roofs on tanks, there is promise of a still more serious problem in the handling of oil from West Texas and the Texas Panhandle, as much of this oil carries with it hydrogen sulphide or its compounds.

## Economy in Movement

While reciprocating pumps driven by oil engines handle most of the oil, especially in the Mid-Continent Field, this year has been marked by the adoption of a number of electrically driven installations. Motor-driven stations have resulted in saving of man power and investment as compared with oil-engine-driven stations. For example, a small electric motor and pump can be operated by the field gager in a gathering system where an additional man might be required with an oil engine. Electrically driven pumps both for large field stations and main-line stations have been installed with economy in time, investment, and, in some cases, in man power. This electric motive power is especially attractive in handling flush oil from new fields where the quantity of oil to be handled is pretty certain to drop off rapidly after a few months.

While electric drive has been put in with reciprocating pumps—the type heretofore used almost exclusively—the use of electric motors has made practicable the adoption of centrifugal pumps for oil-pumping service. This development is something of an innovation in the Mid-Continent Field where centrifugal pumps for pipe-line stations have not been used as they have in California. The direct-connected motor and centrifugal pump has found an economic use in temporarily increasing the capacity of an ordinary pipe line of 40 or 50 miles between the established main-line stations.

Oil engines continue to replace steam equipment at some of the pipe-line stations where steam was originally installed.

Venturi meters as well as liquid meters of other types are being tried out and considered more seriously for the measurement of oil.

There is a continued tendency to replace boilers and steam pumps for more or less temporary field use, with oil- or gasoline-driven portable units.

As in many other branches of the oil industry, welding continues to be more widely used in transportation. Some pipe-line companies are almost standardizing on welded lines; others are using it more widely than ever for river crossings, manifolds, and repairs.

While conservation has been the keynote, the industry has not lacked the extension of pipe lines into new fields. Three trunk pipe lines have been built into the Texas Panhandle and two into the new West Texas fields. These new extensions in the Mid-Continent Field cover considerable mileage of pipe and are built along the same general design considered as good practice in the last few years, having steel pipe operated at about 700

lb. working pressure with stations comprising oil-engine-driven reciprocating pumps. Another line now under construction is designed with electric-motor drive.

While part of the transportation of crude oil from isolated or temporarily congested districts is handled by tank cars on the railroad, the pipe lines continue to be the principal and most economical way to transport crude oil.

The refineries located on the Eastern Seaboard will of course continue to receive the greater portion of their crude-oil supply by tanker. A number of these have been acquired during the past year, either as re-engined Shipping Board vessels or newly constructed ships. Most of these ships are provided with either direct Diesel-engine drives or Diesel-electric drives.

# Progress in Refining

By WALTER SAMANS

THE petroleum refining industry governs the progress in its methods from year to year by the existing conditions, which are ever varying. There is therefore no definite program which can be adhered to for long periods of time, and what may be good practice in one year may be superseded for very good reasons in the next year or thereafter.

The governing factor in progress is supply and demand, the same as it would be for any manufactured article. The influence of the past year's production of crude oils at approximately 20 per cent above the normal, and the uncertainty as to how long this excess production will continue, are bound to affect the viewpoint of the refiner as to the process value of existing and new equipment and the result on sale prices. Under such conditions the equipment available is put to the best possible use, and as in the case of some cracking stills at the present time, it may only be used because it is available and because of the need for disposal of cracking stock, even though the difference in market value between the raw and finished product from this type of still be insufficient to warrant cracking. The natural result of an excess in crude production is lower market prices, as storage of raw products involves considerable expense; and as lower prices of finished products also result, the profits in the business must be the real guide to the refiner in planning new investments.

In considering the progress which has been made during the last year or more, it might be well to divide the subject into five sub-headings as follows:

1 The savings in manufacture which may be obtained
2 The construction and engineering problems
3 The various processes in vogue
4 The developments in the manufacture and use of steam and power, and
5 The research work being done for future development.

### Savings Possible in Manufacture

1 As the profits of a business decline, no matter for what reason, possible savings must be obtained in every branch of manufacture, and this is no less true of the refining industry than in the production of raw materials or in the marketing of the finished products. It is not only necessary to avoid waste wherever possible, but also to increase the yield of the more valuable products.

The crude oil when received at a refinery is stored in tanks of the larger sizes. To cut down evaporation losses, tanks are provided with gas-tight roofs and with vents which restrict the escape of gas and the intake of air as the volume of the oil in the tank changes due to pumping in or to outage, and to temperature changes. The latter action is commonly known as "breathing," and takes place principally between day and night conditions. In addition, these breather vents are provided with a flame arrester, so that in case of fire nearby, or if a tank be struck by lightning and the steel is not ruptured, the flame will not be communicated to the contents of the tank. Sometimes a pressure as high as 1 lb. per sq. in. is maintained on this gas space by these control vents, in which case the roof is built in the shape of a segment of a sphere, commonly known as a dome roof and also termed an umbrella roof. In other cases breather bags, made of balloon material and housed from the weather, are connected with the vapor spaces in one or more tanks so that the breathing may take place in a closed system and gas cannot therefore escape to the air. A similar system, involving the use of a gas holder connecting to a number of tanks in a group, has been used, but the size of the lines required on account of the large volume and low pressure of the gases involved makes the initial cost very high. The principal loss in evaporation—and this applies to finished light material such as gasoline even to a greater extent than to crude—is the absorption of gasoline vapors by the air in contact with the liquid. This quantity varies from 10 to 15 gal. of gasoline for 1000 cu. ft., and as this is a high-priced product, the loss is quite important. Another method used for the conservation of such materials is the installation of floating roofs, which in effect are metal pans properly braced and provided with flexible contact shoes between the shell and the tank. A second type of floating roof consists of a series of pontoons with flexible connections at the joints and also provided with flexible contact shoes against the tank shell. These roofs float on the liquid, the idea being to do away with evaporation by eliminating the air space over the liquid. With lighter distillates under a pan type of floating roof the heat of the sun tends to boil off the lighter fractions in contact with the under side of the roof, the gases escaping at the edge of the pan. To minimize this, the roof may be insulated. Insulation may also be applied on top of the steel roofs of gas-tight tanks where the nature of the contents makes it desirable, and this will restrict the fluctuation in temperature changes, and therefore the breathing losses.

One of the largest savings that has been obtained is in the fuel used under stills, this latter forming approximately 40 per cent of the manufacturing expense. The old type of still, consisting of a horizontal steel shell set on brick or concrete masonry, with more or less structural steel, had an efficiency of from 20 to 30 per cent. The latest types of stills, whether the heating elements consist entirely of tubes or are partly shells, have an efficiency of 60 to 75 per cent. The gains are accomplished by the use of better-constructed furnaces, provided with instruments for better-regulated control of fuel and air, and take advantage of the radiant heat and convection heat in the best possible manner, which minimizes stack losses. The low rate of heat transmission from the flame to the oil inside of a still of the old type—6000 B.t.u. per sq. ft.—has been improved by the increase in velocity of the oil being heated through a pipe coil, and also by the addition of extended surface on the outside of tubes to a maximum of 25,000 B.t.u. per sq. ft., and data are in the hands of manufacturers to enable them to predict fairly accurately the results to be obtained from any given design.

Various types of stokers have been in use for some time on stills of both the old shell type and the later continuous type using forced circulation. Within the last year powdered coal has been applied to the latest type of tube stills with apparent success, resulting in efficiencies equivalent to good refinery boiler practice.

The efficient use of heat is naturally being supplemented by the proper use of insulating materials. This not only provides for layers of insulating brick, or outside insulation of settings, but

also for the covering of all piping and apparatus where radiation is undesirable.

One of the largest of fuel savings in connection with oil distillation has been obtained by the installation of tubular heat exchangers. The early days of such equipment were full of trouble for both the manufacturer and the refiner, due to the inadequate knowledge of this subject compared to steam practice, or that in other industries in which the materials were not handled at high temperatures or did not interfere seriously with heat transfer, and where corrosion was not a serious problem. For the heavier by-products of refining the heat transfer is as low as 10 B.t.u. per sq. ft. per degree of temperature difference, while for the lightest products the value may reach 70 or 80. This matter is further complicated by the limited pressure drops available as required by the process of distillation and the need for space between tubes for cleaning.

The natural low efficiency of heat transfer where oil is on one side of the tube surface and water is used for cooling makes it essential that clean water be used, and some of the refineries are putting in auxiliary coolers in which river water, which may contain a variable percentage of mud and slime, is used to cool deaereated water which operates as a cooling medium for the oil in a closed system. This cuts down the cleaning time and therefore the shutdown periods on the more expensive oil-distilling apparatus.

Naturally the introduction of instruments, both for control of fuel conditions and the specifications of the products, requires a higher class of labor, and to keep down the expense of this part of process, which in total averages 20 per cent of the refinery's manufacturing expense, the stills are built in batteries, and each unit is as large as practicable.

### Construction and Engineering Problems

2 From the construction and engineering standpoint, studies are constantly being made of the possibilities of various materials, of which a great number are on the market, and particularly is this necessary from the standpoint of corrosion. Every crude oil contains sulphur in some form, even though it be a very small percentage in some of the better crudes. Chlorides may also be present in some crudes, which results in the formation of hydrochloric acid, and this must be provided against. Any alkali added in some portion of the refining process may affect certain construction materials which would otherwise be most useful. The various alloys, both ferrous and non-ferrous, are continually studied and tested, and at the high temperatures and pressures prevalent, particularly in cracking, the physical properties of the materials used must also be considered. There must be no uncertainty in the metallurgy of a finished metal that is used in any part of the apparatus, as naturally in a large, expensive unit an enforced shutdown is very expensive.

High-pressure cracking processes have developed the manufacture of forge-welded chambers for this work. These are made in various diameters and over 40 ft. long, with thicknesses varying according to requirements up to $5^1/_2$ or 6 in. The ends are necked down and provided with flanges and covers, and a finished chamber of 52 in. inside diameter and 42 ft. long will weigh from 50 to 70 tons, depending upon the amount of machining that is done, whereas the original ingot from which the forging is made may weigh as much as 200 to 250 tons. These single forgings are being made both in this country and abroad.

Another development within the last few years on such large chambers is an electric-fused welding process in which the welding material is such that air is prevented from acting upon the material being welded. The chambers are made up of plates of the thickness required for considerable length with relation to width, and curved in the width to suit the radius of chamber desired. Chambers of this type have been in use in the Holmes-Manley and other processes and are giving satisfactory results.

Present-day refinery operators must keep pace not only with the market demand but also provide for available space for incoming shipments of crude oil, and this is governed by the kind of equipment and the capacity of tanks available. Every operation is scheduled, and the complications added by the use of pipe or tube heating coils, heat exchangers, condensers, and coolers necessitate that the cleaning of this apparatus be done in the most efficient manner. At the same time repairs must be carefully watched, and this is accomplished by a regular system of inspection, providing not only for the safety of the operators but also for the replacement of worn-out equipment when necessary. All such information is carefully recorded and studies are made for the improvement of conditions.

Protection of every kind must be provided, not only for the operators, for which no expense is spared, but also for the equipment. In consequence construction is now built for permanence and fire resistance, and every enclosed or semi-enclosed space must be properly ventilated. While the ground space occupied by equipment as now constructed may only be 25 per cent of that occupied by equipment of the same capacity some years ago, the structure has reared itself in the air, due to the natural requirements of the process; and whereas the old-type structures, with the exception of stacks, seldom exceeded a height of 25 ft., the apparatus may now extend upward 70 to 90 ft.

The protection of operators and the apparatus as a whole must be supplemented by protection from corrosion, which may occur in the materials used, particularly alloys as above noted, or also in the special coatings provided. Surface applications of metal to metal, or inert compounds applied to surfaces exposed to hot oil and vapors, are used, and in some types of stills such surface protection not only provides against corrosion but also against the adherence of carbon deposits. This is very essential in maintaining an efficient heat transfer on heating elements, for as soon as this stops or is hindered seriously the heating elements will increase in temperature until they are no longer able to carry the load, and the apparatus must be shut down.

With temperatures ranging from 800 to 1000 deg. fahr. and pressures varying from 0.5 in. or less of mercury to 1200 lb. per sq. in., it is natural to conclude that the problems of the oil refiner will never be entirely solved.

### The Various Processes in Vogue

3 The processes selected by the refiner for obtaining marketable products from the crude are naturally dictated by supply and demand, and by the economies obtainable. The quality of the product is of first importance, as nowadays the competition and the purchaser's knowledge of his requirements make it impossible to maintain sales except by strict adherence to specifications. Crude oil being a mixture of a number of combinations of carbon and hydrogen having different boiling points, may naturally be separated by distillation. Every one of these compounds, however, may be broken up into other compounds by overheating during this process, and there is a fairly definite range of pressures and temperatures under which these conditions will occur.

Before the advent of internal-combustion engines, particularly gasoline engines, there was no great proportional demand for naphthas, or what we now term motor gasoline. Cracking for a purpose was unknown, and all crude oil was distilled in batches and fractionated by gradually increasing the temperature of the oil and in an approximate way boiling off each product in turn. Impossible uniformity of heat distribution, due to the crudeness of the apparatus, resulted in overlapping of the various fractions, and the distilled products so obtained had to be rerun,

that is, again passed through the evaporating and condensing process. Each run resulted in losses that were unavoidable. The application of continuous distillation, and later the use of fractionating columns, has resulted in the modern pipe still, which produces continuously various fractions from the crude oil to desired specifications with rerunning reduced to a minimum and without scarcely any further processing except treating, and consequently with greater percentages of recovery of various products.

The heavier the products the more apt they are to crack. That is, the lubricating oils will be affected in this way at lower temperatures and pressures than kerosene and naphthas. This has resulted in the development of the vacuum distillation process, which lowers the boiling point of the liquids and at the same time gives greater yields which are claimed to be of better quality. With present knowledge in the foundry and machine shop, it is possible to produce apparatus in which a very high vacuum can be maintained and which will operate efficiently for long periods of time. The use of multi-stage thermo-compressors makes it possible to recover the steam and further improve the overall efficiency of the apparatus.

While the fractional distillations above mentioned are carried on at a pressure close to atmosphere or in partial vacuum, the development of the gasoline engine has in past years made it necessary to greatly increase the yield of the lighter fractions in proportion to the crude oil available and to the other products desired. This naturally resulted in the development of cracking processes which require fairly definite temperatures, and the maintenance of high corresponding pressures, if the cracking is to take place in apparatus of reasonable size and without evaporation. This involves high-pressure pumps for charging those fractions of the crude of which a surplus existed, mainly gas oil, and the use of digesting or reaction chambers in which the process can be completed after the oil has been heated to the proper temperature. While very little is known of what actually takes place, it was indicated that the time element was of some importance, and that the action of cracking was not instantaneous. Following this phase of the operation the pressure is released, and the mixture of gasoline obtained, together with some carbon and fixed gas, and the unaffected portion of the charge are expanded into an evaporating chamber and from there carried into a fractionating tower. This consists of a vertical shell equipped with a number of trays arranged in tiers, these trays having openings covered with caps. On each tray a certain amount of liquid collects, through which the steam and vapors have to pass, distribution of vapor through the liquid being accomplished by serrated edges on the bottom of the caps. This apparatus is commonly know as a bubble tower, and as the temperature drops from the bottom of the tower upward, the light distillates are separated from the lower-boiling compounds, so that at the top of the tower steam and practically pure gasoline vapor are taken off and led to the condensing apparatus. In such a tower used with fractionating pipe stills, other products are removed at intermediate trays; and the heaviest fraction, commonly termed "bottoms," is reduced to the lowest possible percentage. During the past few years it has been found that crude oil can be charged direct into cracking apparatus, and the natural naphtha and the cracked naphtha can thereby be removed in one operation with possibly less loss than by carrying out the fractionation of the natural naphtha separately from the cracking apparatus.

It can readily be seen that as crudes vary in their natural components and the demands of the market also vary for various finished products, the refiner has a constantly changing problem, demanding the best and most economical method of refining. During the last year the number of fractionating stills—commonly known as pipe stills due to the type of heating element—and the number of cracking stills have been greatly increased, although the excess production of crude has reduced the number of cracking stills that might have been built.

The vapor-phase type of cracking stills and the aluminum-chloride process of cracking are also in successful use, but have not had the same growth in number as the liquid-phase type of cracking stills. Vapor-phase cracking may have a special use in producing gasoline with fewer detonating characteristics.

All products as they are obtained from the first distillation of crude oil must be treated in some way. Sulphuric acid is still being used for decolorizing, but there has been considerable development in the application of clay filtration. The old method by percolating filters is being superseded on some oils by fine-clay contact treatment. The principle of this process depends upon mixing this material with the oils at proper temperatures in stirring agitators and then allowing it to settle, the number of stages of mixing and settling depending upon the refinement desired. A light acid treatment usually precedes the clay treatment.

The reconditioning of spent clay from the filtration processes has been successively accomplished by means of rotary kilns and gravity-flow driers, and in the latest plants the Herreschoff and Wedge furnaces are used, resulting in longer life for the clay.

The Edelanea process of refining, involving the extraction with liquid sulphur dioxide, is gaining headway on the Pacific Coast, and its wider use may be expected.

The use of the centrifugal method of dewaxing has become more general, and its application has been broadened.

It has been found that gasoline vapor can be treated by passing it through a fullers' earth filter, and this is superior to sulphuric-acid treatment of liquid gasoline, as the latter tends to destroy some of the anti-detonating compounds.

### Developments in Manufacture and Use of Steam and Power

4 With reference to steam and power requirements, the older types of refineries had use for a large quantity of process steam, and it was natural that their boiler plants were built mainly for this purpose, generating steam at pressures from 80 to 250 lb. and obtaining electric power by means of turbines working on 10 to 15 lb. back pressure, or using the bleeder type of turbines suitable for variable steam conditions.

The process steam required for distillation in the new type of stills is about one-third less per barrel of oil distilled than formerly, and at the same time, on account of the higher pressure required for charging pumps on crude stills and the extremely high-pressure charging pumps used on cracking stills, electric power applied through gear drives is coming rapidly into use, and more generating capacity is thereby required.

The development of high-pressure boilers and higher pressure in distribution mains for steam over widely extended plants, and the resulting improved economy, has benefited large refineries in the same way it has other industries. It has even been found desirable in some plants to generate power by means of oil engines. In the use of cracking processes the quantity of gas produced has increased, and naturally the installation of stripping plants by means of which gasoline vapors are removed from the still gas before it is burned, has made gas-engine drives possible for air and gas compressors and similar service, particularly at points far removed from a supply of steam or electricity.

The modern cracking still may require a hot-oil pump with a forged-steel liquid end handling about 180 gal. of oil per min. and operating at 650 deg. fahr., and 1200 to 1600 lb. pressure, and such pumps may be steam driven with compound steam ends, or motor driven, in which case variable-speed motors are preferable. Where steam is available in suitable pressures and

quantities, a steam pump is preferred, but as the power pumps have been found to operate very smoothly under such conditions and with some improvement in economy, they may in the end be found more suitable.

5 Regardless of where crude oil is obtained and in what quantities it may be obtained compared to the demands for finished products, the necessity of making profits against severe competition calls imperatively for continued research work toward improvement.

### Research Work Under Way

The Bergius process for obtaining products similar to those obtained from petroleum by distillation of coal under 200 atmospheres has found favor abroad, due to the peculiar situation there with reference to the crude market, and in the past year the rights on this process for this country have been obtained by the Standard Oil Company of New Jersey, although it is not expected that the process will become commercially feasible for some years to come.

In the application of radiant heat, several stills are under construction in which the oil heater tubes form the inner enclosure of the combustion chamber.

Research work is being done toward the recovery of a greater portion of the by-product gas from petroleum distillation than is now obtained by stripping processes, for use in motor fuels.

While the number of small plants obtaining petroleum products from shale oil is increasing, the proportion of these products, compared to the total market requirements, is very small.

Summarizing the entire field of refining, the last few years have indicated remarkable strides toward improvement, and the application of the latest methods in process, construction materials, and the actual use of apparatus in operation has become a highly technical subject.

# General Heat-Transfer Formulas for Conduction and Convection

By EDWIN R. COX,[1] LOS ANGELES, CALIF.

Only within the last few years has the subject of heat transfer by forced convection been placed upon a fairly sound basis, although Osborne Reynolds[2] in 1874 indicated the way. He derived by dimensional reasoning a function $dvG/\mu$ as an index of critical velocity, and plotted the coefficient of friction for pipe-line flow against this function. He also suggested that this function should affect heat transfer, but neglected to reconcile the other variables in his equation by the same dimensional reasoning. Hence his suggestion did not bear fruit for many years.

Nusselt[3] was the first to derive (1909) a complete rational equation by dimensional reasoning. In order to compare the different formulas, the following symbols have been used throughout:

- $h$ = transfer through one fluid film, in B.t.u. per sq. ft. per hr. per deg. fahr.
- $d$ = inside diameter of tube in inches
- $k$ = conductivity of fluid in B.t.u. per foot cube, per hour, per deg. fahr.
- $v$ = velocity, ft. per sec.
- $G$ = specific gravity compared with water
- $\mu$ = viscosity in poises
- $C_p$ = specific heat at constant pressure
- $C$ = coefficient, in general different for each equation, unless identified by a subscript.

With this nomenclature, Nusselt's formula becomes

$$\frac{hd}{k} = C_1\left(\frac{dvG}{\mu}\right)^{\alpha}\left(\frac{\mu C_p}{k}\right)^{\beta} \qquad [1]$$

He finds $\alpha = 0.786$. For simplicity he makes $\alpha = \beta$, thus eliminating $\mu$. This serves satisfactorily for gases but would not do for viscous liquids or even for water through a considerable range.

McAdams and Frost[4] note Nusselt's formula but make $\beta = 0$ for liquids. With $\alpha = 0.796$, this accords well with tests on water and light oils.

Rice[5] seems to have been the first to use the entire formula and finds $\alpha = 0.833$ and $\beta = 0.500$. He plots a large number of tests upon air and water and they accord fairly well. No tests were included for viscous liquids. $\beta$ is derived from Soennecken's tests with water. Plotting $h$ against $\mu$ for equal velocities, Rice finds $h = c/\mu^{0.445}$, other things being equal. But 0.445 represents the net effect of viscosity, or $0.445 = \alpha - \beta$. If $\alpha = 0.833$, $\beta = 0.833 - 0.445 = 0.388$. If we take $\beta = {}^1/_3$ and $\alpha = {}^5/_6$, $\alpha - \beta = {}^1/_2$. If we draw lines to this exponent through the points in Rice's chart for Soennecken's data, they seem to include the points well within the apparent experimental error. The writer corrected Rice's results to this exponent and the results accorded somewhat better, though not strikingly so. With $\beta = {}^1/_2$, Rice obtains a coefficient $k_0$ of 63.5. The tabulated data, using Peter's formula, shows a probable error of 2.2 per cent for $k_0$ or 15.2 per cent for a single observation. Correcting to $\beta = {}^1/_3$, the coefficient is 52.4 with a probable error of 1.85 per cent for $k_0$ or 12.8 per cent for an observation.

Rice expresses his formula entirely in c.g.s. units, some electrical, as follows:

$$W_e = \frac{Ak\,\Delta t}{K_0 D}\left(\frac{\mu C_p}{K}\right)^{\beta}\left(\frac{\rho D v}{\mu}\right)^{\alpha} \text{ watts}$$

which may be transformed to

$$\frac{W_e D}{A\,\Delta t k} = \frac{D}{B} = \frac{1}{K_0}\left(\frac{\rho D V}{\mu}\right)^{\alpha}\left(\frac{\mu C_p}{K}\right)^{\beta}$$

For translating into our units we find that

$$\frac{hd}{k} = 12\left(\frac{W_e D}{A\,\Delta t k}\right) = \frac{12}{B/D}$$

$$\frac{dvG}{\mu} = \frac{1}{77.42}\left(\frac{\rho D v_0}{\mu_0}\right)$$

$$\frac{\mu c_p}{k} = \frac{1}{241.9}\left(\frac{\mu_0 c_p}{k_0}\right)$$

$$C_1 = \frac{2804}{k_0} \text{ for } \beta = {}^1/_3$$

$$C'_1 = \frac{7000}{k_0} \text{ for } \beta = {}^1/_2$$

Hence in our units the Rice equation becomes

$$\frac{hd}{k} = 53.5\left(\frac{dvG}{\mu}\right)^{5/6}\left(\frac{\mu C_p}{k}\right)^{1/3} \qquad [2]$$

or

$$\frac{hd}{k} = 110.2\left(\frac{dvG}{\mu}\right)^{5/6}\left(\frac{\mu C_p}{k}\right)^{1/2}$$

Equation [2] would seem to be the best approximation to be obtained from the data of Rice.

McAdams and Frost[5] derive the formula

$$\frac{hD}{k} = 22.6\left(\frac{Du\rho}{z}\right)^{0.796}$$

where $D$ = diameter in in.
$u$ = velocity in ft. per sec. and
$z$ = $100\mu$.

If we take a middle point in their chart where $\frac{hD}{k} = 1250$ and $\frac{Du\rho}{z} = 150$ and draw a line through this point with the inclination $\alpha = {}^5/_6$, we find that it satisfies the points substantially as well as the 0.796 line. This would give the equation in our units

$$\frac{hd}{k} = 13.73\left(\frac{dvG}{\mu}\right)^{5/6}$$

[1] Engineer, California Gasoline Co. Mem. A.S.M.E.

[2] Proc. Manchester Lit. and Phil. Soc., vol. 14, 1874.

[3] *Zeitschrift des Vereines deutscher Ingenieure*, Oct. 23 and 30, 1909.

[4] *Journal of Industrial and Engineering Chemistry*, vol. 14 (1922), p. 1101.

[5] *Journal of Industrial and Engineering Chemistry*, vol. 16 (1924), p. 460.

Presented at the Annual Meeting, New York, Dec. 5 to 8, 1927, of The American Society of Mechanical Engineers.

In plotting these data upon his chart, Rice assumes a mean value of $\frac{k}{\mu c_p} = 0.25$ in c.g.s. units, which would be 60.48 in our units. Hence $C_1$ for the McAdams and Frost data would be $13.73 \times (60.48)^{1/3} = 54.0$.

Perhaps the most elaborate and thorough tests upon heat transfer that have been published are those made by the Babcock & Wilcox Company[6] upon flue gases. The author has taken four points upon their chart, rather wide apart in velocity and temperature and converted them to our units in Table 1. These give values of $C_1$ = 54.4, 51.8, 53.2, and 52.8 with a mean value of 53.1. Comparing this with the value obtained from Rice, 53.5, and from McAdams and Frost, 54.0, the agreement is very good and indicates 53.5 as the best estimate.

TABLE 1

| | Uncored, $d$ = 2 in. | | | | Cored, $d_e$ = 1 in. | | | (1 in. diam., core) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\theta$, deg. fahr. | 400 | 400 | 2000 | 2000 | 400 | 400 | 400 | 2000 | 2000 | 2000 |
| $W/A$ | 6700 | 11800 | 6700 | 11800 | 8000 | 12000 | 16000 | 8000 | 12000 | 16000 |
| $h$ | 7.23 | 11.10 | 9.72 | 15.45 | 10.15 | 13.75 | 17.4 | 14.45 | 20.15 | 26.00 |
| $k$ | 0.018 | 0.018 | 0.0291 | 0.0291 | 0.018 | 0.018 | 0.018 | 0.0291 | 0.0291 | 0.0291 |
| $1/\mu$ | 4005 | 4005 | 3217 | 3217 | 4005 | 4005 | 4005 | 3217 | 3217 | 3217 |
| $k/\mu C_p$ | 272 | 272 | 260 | 260 | 272 | 272 | 272 | 260 | 260 | 260 |
| $hd/k$ | 804 | 1233 | 668 | 1062 | 564 | 764 | 966 | 496 | 693 | 894 |
| $dvg/\mu$ | 238.5 | 421.0 | 191.8 | 337.5 | 142.6 | 214.0 | 285.2 | 114.5 | 171.8 | 229.0 |
| $\left(\frac{dvG}{\mu}\right)^{4/5}$ | 95.8 | 154.0 | 80.0 | 128.0 | 62.4 | 87.5 | 111.3 | 52.0 | 73.0 | 92.5 |
| $\left(\frac{k}{\mu C_p}\right)^{1/3}$ | 6.48 | 6.48 | 6.38 | 6.38 | 6.48 | 6.48 | 6.48 | 6.38 | 6.38 | 6.38 |
| $C_1$ | 54.4 | 51.8 | 53.2 | 52.9 | 58.5 | 56.6 | 56.1 | 60.9 | 60.5 | 61.6 |

NOTE: In the report on these tests $h$ is plotted against $W/A$ where $A$ is cross-section of tube in square feet. In the above calculations, the following assumptions have been made. Composition of flue gas (by weight): $CO_2$ = 0.149, O = 0.068, N = 0.704, $H_2O$ = 0.079. The characteristics are calculated by mol fraction.

At 180 deg. fahr., $1/\mu = 4740$, $k = 0.0148$, $C_p = 0.2506$, $k/\mu C_p = 280$
At 580 deg. fahr., $1/\mu = 3270$, $k = 0.0212$, $C_p = 0.2620$, $k/\mu C_p = 265$
At 2180 deg. fahr., $1/\mu = 1694$, $k = 0.0434$, $C_p = 0.3079$, $k/\mu C_p = 239$
The temperature of the tube wall is maintained at 180 deg. fahr.

TABLE 2 OIL COOLING

| Character of oil | Rerun bottoms | | | | Residuum | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Test number | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 |
| Gravity of oil, °API | 37 | 37 | 37 | 37 | 20 | 19 | 19 | 19 | 19 |
| $W$, lb. per hr | 182.3 | 745 | 1640 | 2490 | 351 | 439 | 796 | 1362 | 1615 |
| Temperature oil in, deg. fahr | 168.0 | 264 | 297.5 | 327 | 153.7 | 173.2 | 233.8 | 264.4 | 247.0 |
| Temperature oil out, deg. fahr | 123.3 | 189 | 223 | 250 | 140.8 | 159.4 | 220.1 | 246.2 | 233.6 |
| Temperature water in, deg. fahr | 60.0 | 60 | 60 | 59 | 60 | 60.7 | 61.0 | 61.0 | 60.0 |
| Temperature water out, deg. fahr | 61.0 | 67.9 | 76.8 | 87 | 61 | 61.7 | 62.8 | 64.8 | 63.4 |
| Temperature tube wall, deg. fahr | 69.2 | 112 | 168 | 224 | 64 | 66 | 70.6 | 82.4 | 78.9 |
| $R = 1000/U$ | 29.3 | 8.28 | 4.50 | 3.22 | 55.5 | 50.2 | 43.7 | 22.5 | 23.8 |
| $R_w$ = water film and tube wall | 2.5 | 2.46 | 2.34 | 2.26 | 2.4 | 2.3 | 2.3 | 2.3 | 2.3 |
| $R_o$ = oil film | 26.8 | 5.82 | 2.16 | 0.96 | 53.1 | 47.9 | 41.4 | 20.2 | 21.5 |
| $F = 1/\mu$ (mean) | 77.3 | 120 | 160 | 201 | 1.095 | 0.69 | 0.882 | 1.41 | 0.81 |
| $dvG/\mu$ | 22.0 | 139 | 410 | 780 | 0.60 | 0.47 | 1.09 | 3.00 | 2.04 |
| $C_1$ | 48.3 | 55 | 66 | 94 | 118 | 138 | 85 | 89 | 95 |

TABLE 3 OIL HEATING

| Character of oil | Distillate | | | | | Crude | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Test number | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 |
| Gravity of oil, °API | 40 | 40 | 40 | 40 | 40 | 34 | 25 | 24 | 23 | 23 |
| $W$ = lb. per hr | 59.1 | 200.5 | 719 | 1852 | 3060 | 132.6 | 198.7 | 600 | 2000 | 3415 |
| Temperature oil in, deg. fahr | 76 | 74 | 72 | 75 | 77 | 65 | 66 | 65 | 59 | 58 |
| Temperature oil out, deg. fahr | 270 | 195 | 166 | 164 | 160 | 192 | 162 | 102 | 85 | 85 |
| Temperature steam in, deg. fahr | 314 | 311 | 311 | 309 | 308 | 313 | 310 | 310 | 314 | 313 |
| Temperature steam out, deg. fahr | 305 | 299 | 305 | 304 | 303 | 305 | 305 | 305 | 309 | 308 |
| Temperature tube wall, deg. fahr | 307 | 301 | 298 | 283 | 270 | 307 | 305 | 304 | 304 | 298 |
| $R = 1000/U$ | 28.2 | 19.65 | 7.8 | 3.23 | 2.094 | 29.8 | 28.8 | 29.2 | 13.43 | 7.49 |
| $R_s$ = steam film and tube wall | 0.4 | 0.40 | 0.4 | 0.40 | 0.40 | 0.4 | 0.4 | 0.4 | 0.40 | 0.40 |
| $R_o$ = oil film | 27.8 | 19.25 | 7.4 | 2.83 | 1.694 | 29.4 | 28.4 | 28.8 | 13.03 | 7.09 |
| $F = 1/\mu$ (mean) | 207 | 180 | 167 | 163 | 160 | 132 | 28.3 | 11.6 | 6.0 | 5.8 |
| $dvG/\mu$ | 19.1 | 56.1 | 187.0 | 470 | 762 | 27.3 | 8.77 | 10.85 | 18.7 | 30.9 |
| $C_1$ | 69.5 | 38.9 | 41.9 | 43.1 | 48.1 | 42.3 | 69.6 | 43.0 | 48.5 | 58 |

NOTE: $V$, $R$, $R_w$, $R_s$, and $h$ are based on outside surface. This is reconciled by taking outside diameter, 0.625 in., in $hd/k$. $k$ is taken as 0.086. $dvG/\mu$ is calculated for inside of tube and $C_1$ applies to inside film. The logarithmic mean is used for $\Theta$ in calculating $U$.

In Table 1 are also included tests for cored tubes, in endeavoring to determine the true value of the effective diameter $d_e$ to be used in applying the formula to annular spaces or the space around a nest of tubes. The author assumed at one time that $d_e$ should be $4a/P$ where $a$ is the area and $P$ the total wetted perimeter, in $dvG/\mu$; and should be $4a/P'$, where $P'$ is the perimeter of conducting surface only, in $hd/k$. Although this gave consistent values for a nest of tubes, where $P$ and $P'$ did not differ greatly, it gave too large values for $d_e$ in double-pipe exchangers. The Babcock & Wilcox data for cored tubes would give $C_1$ = 88.5 if we used $P'$, instead of 59.0 if we used $P$. This seems to prove conclusively that $4a/P$ is nearer the true value, although the difference between 53.1 and 59.0 is great enough to indicate possibly some intermediate value, such as

$$d_e = \frac{4a}{P}\left(\frac{P}{P'}\right)^x$$

To determine $x$ would require more data than is available at present.

Another point about which there has been serious question is, Where should the viscosity of the fluid be determined? Calling the mean temperature of the fluid $t_1$ and that of the tube wall $t_2$, McAdams and Frost in some of their earlier work took the viscosity at $t_2$. Later they adopted $(t_1 + t_2)/2$ as the determining temperature and Rice also uses this value. Rice, from King's data, suggests $\sqrt{t_1 t_2}$ may be the true value. In dealing with fluids whose viscosity changes rapidly with temperature, such as heavy petroleum fractions, the writer obtained the most consistent results by taking $\mu = (\mu_1 + \mu_2)/2$ where $\mu_1$ and $\mu_2$ are taken at $t_1$ and $t_2$, respectively. This is hardly necessary when dealing with water or light oils, but when heating crude oil or cooling residuum, the distinction becomes quite important. Here $\mu_1$ and $\mu_2$ vary twenty and thirtyfold, and in fact the main problem is to determine the proper value of $\mu$ to use in the formula.

Unfortunately very little has been published in regard to the

[6] Experiments on the Rate of Heat Transfer from a Hot Gas to a Cooler Metallic Surface, Babcock and Wilcox Co., 1916, pp. 62 and 64.

conductance of oil films. In Tables 2 and 3 are given the results of some tests which are not as good as could be desired, mainly because the viscosity of the oils was not determined directly, but taken from a chart of similar oils, and the temperatures of the tube wall were not measured, but calculated. Moreover they are strictly field tests made rather hastily for a certain purpose, without calibrating instruments, or taking other precautions for accuracy as would be done in laboratory work, with which it is not comparable. The data are only included because nothing better is available.[7]

These tests were all made with a $^5/_8$-in. outside diameter No. 18 B.w.g. Admiralty mixture tube, 8.81 ft. long, 1.445 sq. ft. outside surface, enclosed in a standard $1^1/_4$-in. pipe. The oil was passed through the tube and steam or water through the annular space. Tests Nos. 59–63 are strictly stream line and are included to show the rise in value of $C_1$ with velocities less than the critical, which in these units is at approximately $dvG/\mu = 12.3$. Omitting these tests the mean value of $C_1$ is 54.7. Test No. 58 is unreliable inasmuch as the calculated value of $R_w$ is over twice as great as the value of $R_0$, obtained by difference, and, hence, a small error in $R_w$ would be magnified in $R_0$. Omitting this test, the mean value of $C_1$ would be 51.7. This is sufficient to indicate the general conformity of oil tests with those of air and water.

Assuming then that the Nusselt-Rice equation is the best available expression of the film concept of heat transfer, it remains to adapt this to a more convenient form for the practical design of heat-transfer apparatus. The most important practical considerations are cost of apparatus and cost of operation. Of the latter the most important item is pressure drop through the apparatus. As is generally known, we are able to secure almost any rate of conductance within reason if we are willing to expend sufficient power in forcing the fluids through the tubes. Hence pressure drop is a prime consideration. We may further simplify the problem by confining it to the conventional types of exchangers, either the double pipe, or the multitubular, where one fluid is forced through the inner tube or tubes, and the other through the surrounding space. In both cases the larger pressure drop is through the tubes and we may confine our attention to this. In order to relate this pressure drop to the overall conductance we must express the latter, $U$, as a function of the conductance of the inner film,

$$U = C_2 h$$

or

$$\frac{Ud}{k} = C_1C_2\left(\frac{dvG}{\mu}\right)^{\alpha}\left(\frac{\mu C_p}{k}\right)^{\beta} \quad \ldots\ldots\ldots\ldots [3]$$

where the characteristic terms apply only to the inside of the tubes. This is equivalent to assuming that if we increase the velocity of the fluid inside the tubes, we also increase the outside velocity at the same rate, and that the resistance of the tube wall is negligible. This is sufficiently approximate for most cases. If greater accuracy is required, $C_2$ may be treated as a variable and related to $v$ by tests for each group of cases.

The total heat transferred in B.t.u. per hour may be expressed as

$$H = W\Delta C_p = AU\Theta \quad \ldots\ldots\ldots\ldots [4]$$

where $W$ is pounds per hour per tube, $\Delta$ the temperature range of the fluid, $C_p$ its specific heat, $A$ the inside conducting surface in square feet, and $\Theta$ the mean temperature difference between the two fluids.

For pressure drop we have the Chézy formula

$$p = \frac{f_1 v^2 GL}{d}$$

where $f_1$ is a function of $dvG/\mu$ usually expressed by a chart, such as that of Wilson, McAdams, and Seltzer.[8] If we consider the usual range of $dvG/\mu$ for liquids, and that for gases we may, within each of these ranges, express $f_1$ in terms of $dvG/\mu$ with sufficient accuracy, as

$$f_1 = C_4\left(\frac{\mu}{dvG}\right)^{\gamma}$$

This is well within the error introduced by varying roughness of tubes. In order to use the same units in the general equations which follow, we may substitute as follows:

$$v = \frac{W}{1226\,d^2G}, \quad F = \frac{1}{\mu}, \quad \frac{dvG}{\mu} = \frac{WF}{1226d}, \quad A = \frac{\pi dL}{12}.$$

From [3] we have

$$U = \frac{C_1C_2}{(1226)^{\alpha}}\left(\frac{k}{d}\right)\left(\frac{WF}{d}\right)^{\alpha}\left(\frac{C_p}{Fk}\right)^{\beta}$$

or

$$U = \frac{C_1C_2}{(1226)^{\alpha}} W^{\alpha}F^{\alpha-\beta}K^{1-\beta}C_p{}^{\beta}d^{-\alpha-1} \quad \ldots\ldots [5]$$

For pressure drop,

$$p = \frac{f_2W^2L}{d^5G} \quad \text{and} \quad f_2 = \frac{C_5 d^{\gamma}}{W^{\gamma}F^{\gamma}}$$

or

$$p = \frac{C_5W^{2-\gamma}L}{d^{5-\gamma}F^{\gamma}G} \quad \ldots\ldots\ldots\ldots\ldots\ldots [6]$$

From [4] we have

$$W = \frac{\pi}{12}\,\frac{U\Theta dL}{\Delta C_p}$$

or

$$L = \frac{12}{\pi}\,\frac{W\Delta C_p}{dU\Theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots [7]$$

This gives us three fundamental equations [5], [6], and [7]. We may consider the fluid characteristics $F$, $G$, $k$, and $C_p$; the pressure drop $p$; and the temperature relations $\Delta$ and $\Theta$ as fixed by the requirements of a given design. This leaves $U$, $L$, and $d$ subject to variation in design; also $W$, since we may use any number of tubes in multiple. Since we have three independent equations we may eliminate any two of these variables and derive a relation between the other two.

Eliminating $W$ and $L$ we have

$$U = \left\{\frac{C_1C_2}{(1226)^{\alpha}}\right\}^{\frac{3-\gamma}{3-\alpha-\gamma}}\left(\frac{\pi}{12C_5}\right)^{\frac{\alpha}{3-\alpha-\gamma}}\left(\frac{Gp\Theta}{\Delta}\right)^{\frac{\alpha}{3-\alpha-\gamma}}$$

$$F^{\frac{3(\alpha-\beta)+\beta\gamma}{3-\alpha-\gamma}}\,d^{\frac{3(\alpha-1)+\gamma}{3-\alpha-\gamma}}\,k^{\frac{(3-\gamma)(1-\beta)}{3-\alpha-\gamma}}\,C_p{}^{\frac{(3-\gamma)\beta-\alpha}{3-\alpha-\gamma}} \quad \ldots\ldots [8]$$

Eliminating $U$ and $L$ gives

$$W = \left\{\frac{\pi C_1C_2}{12\times(1226)^{\alpha}C_5}\right\}^{\frac{1}{3-\alpha-\gamma}}\left(\frac{Gp\Theta}{\Delta}\right)^{\frac{1}{3-\alpha-\gamma}}F^{\frac{\alpha-\beta+\gamma}{3-\alpha-\gamma}}$$

$$d^{\frac{5-\alpha-\gamma}{3-\alpha-\gamma}}\left(\frac{k}{C_p}\right)^{\frac{1-\beta}{3-\alpha-\gamma}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [9]$$

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[7] Since this paper was prepared it has been brought to the attention of the writer that Whitman and Morris have presented to the American Chemical Society some very valuable data on the heating and cooling of oils. It is to be hoped that this will help clear up the all-important problem of viscosity effect.

[8] *Journal of Industrial and Engineering Chemistry*, vol. 14 (1922), p. 105.

Eliminating $U$ and $W$ and solving for $L$,

$$L = \left\{ \frac{\pi C_1 C_2}{12 \times (1226)^{\alpha}} \right\}^{\frac{\gamma-2}{3-\alpha-\gamma}} C_5^{\frac{\alpha-1}{3-\alpha-\gamma}} (Gp)^{\frac{1-\alpha}{3-\alpha-\gamma}} \left(\frac{\Delta}{\Theta}\right)^{\frac{2-\gamma}{3-\alpha-\gamma}}$$

$$F^{\frac{2(\beta-\alpha)+\gamma(1-\beta)}{3-\alpha-\gamma}} d^{\frac{5-3\alpha-\gamma}{3-\alpha-\gamma}} \left(\frac{k}{C_p}\right)^{\frac{(2-\gamma)(\beta-1)}{3-\alpha-\gamma}} \quad \ldots\ldots\ldots [10]$$

Or, solving for $\Delta/\Theta$,

$$\frac{\Delta}{\Theta} = \left\{ \frac{\pi C_1 C_2}{12 \times (1226)^{\alpha}} \right\} C_5^{\frac{1-\alpha}{2-\gamma}} (Gp)^{\frac{\alpha-1}{2-\gamma}} L^{\frac{3-\alpha-\gamma}{2-\gamma}}$$

$$F^{\frac{2(\alpha-\beta)+\gamma(\beta-1)}{2-\gamma}} d^{\frac{3\alpha+\gamma-5}{2-\gamma}} \left(\frac{k}{C_p}\right)^{1-\beta} \quad \ldots\ldots\ldots [11]$$

These equations are quite general and may be used for any determinations made in the form of the Nusselt-Rice equation, and for any portion of the $f$ vs. $dvG/\mu$ chart.

For the usual range of $dvG/\mu$ found in dealing with oil or water, $\gamma$ is approximately 0.264, and for gas or air, 0.162, making the equations for pressure drop

$$p = \frac{0.00765}{F^{0.264}} \frac{(W/1000)^{1.736} L}{d^{4.736} G} \text{ for liquids} \ldots\ldots\ldots [12]$$

$$p = \frac{0.00404 \, (W/1000)^{1.838} L}{F^{0.162} d^{4.838} G} \text{ for gases} \ldots\ldots\ldots [13]$$

Hence $C_5$ becomes $\dfrac{0.00765}{(1000)^{1.736}}$ for liquids and $\dfrac{0.00404}{(1000)^{1.836}}$ for gases.

Taking $C_1 = 53.5$, $\alpha = {}^5/_6$, $\beta = {}^1/_3$, and $\gamma$ and $C_5$ as above, we have two sets of equations, as follows.

*For Liquids:*

$$U = 54.5 \, C_2^{1.439} \left(\frac{Gp\Theta}{\Delta}\right)^{0.438} F^{0.834} d^{-0.124} k^{0.959} C_p^{0.0414} \ldots [14]$$

$$W = 1247 \, C_2^{0.525} \left(\frac{Gp\Theta}{\Delta}\right)^{0.525} F^{0.401} d^{2.05} \left(\frac{k}{C_p}\right)^{0.35} \ldots [15]$$

$$L = \frac{87.6}{C_2^{0.912}} (Gp)^{0.0875} \left(\frac{\Delta}{\Theta}\right)^{0.912} F^{-0.433} d^{1.175} \left(\frac{C_p}{k}\right)^{0.608} \ldots [16]$$

$$\frac{\Delta}{\Theta} = \frac{1}{135.1} C_2 (Gp)^{-0.096} L^{1.096} F^{0.475} d^{-1.288} \left(\frac{k}{C_p}\right)^{0.667} \ldots [17]$$

*For Gases:*

$$U = 40. C_2^{1.415} \left(\frac{Gp\Theta}{\Delta}\right)^{0.415} F^{0.775} d^{-0.169} k^{0.944} C_p^{0.0563} \ldots [18]$$

$$W = 876. C_2^{0.499} \left(\frac{Gp\Theta}{\Delta}\right)^{0.498} F^{0.330} d^{2.00} \left(\frac{k}{C_p}\right)^{0.332} \ldots [19]$$

$$L = \frac{82.5}{C_2^{0.916}} (Gp)^{0.083} \left(\frac{\Delta}{\Theta}\right)^{0.916} F^{-0.445} d^{1.168} \left(\frac{C_p}{k}\right)^{0.611} \ldots [20]$$

$$\frac{\Delta}{\Theta} = \frac{C_2}{123.3} (Gp)^{-0.0908} L^{1.092} F^{0.485} d^{-1.272} \left(\frac{k}{C_p}\right)^{0.667} \ldots [21]$$

These equations are convenient for ascertaining the net effect of varying one condition while all others remain constant. From Equation [14] and Equation [18] it is evident that, other things being equal, the smallest practicable tube will give the highest transfer rate. If, then, we know the cost per square foot of an exchanger when made of tubes of different sizes, and we multiply each unit cost by the corresponding $d^{0.124}$, the products will be proportional to costs per B.t.u. per degree per hour, and will indicate the optimum size.

Having ascertained the most economical size of tube for a given purpose, the only other feature we can alter in a given set of conditions is the pressure drop. The most economical pressure drop $p_m$ is the one which affords the minimum annual cost $Y$. This is made up of two components $Y_1$, the annual charge on the investment including interest, depreciation, and upkeep, and $Y_2$, the annual cost of pumping or forcing the fluids through the exchanger. Since the surface required is inversely proportional to $U$ and $U$ is directly proportional to some power $e$ of the pressure drop $p$, we may write

$$Y = \frac{C_6 q}{p^e}$$

$C_6$ is best determined by direct test upon an exchanger of similar type. If this exchanger handles $q_0$ gallons per minute with a pressure drop of $p_0$ and a yearly investment charge of $Y_0$, and we wish to design one to handle $q$ gallons per minute, we have

$$Y_0 = \frac{C_6 q_0}{p_0^e}$$

or

$$C_6 = \frac{Y_0 p_0^e}{q_0}$$

Similarly we may determine the pumping charge. Since the power required is proportional to $pq$, we may write

$$Y'_0 = C_7 p_0 q_0$$

and determine $C_7$ by

$$C_7 = \frac{Y_0'}{p_0 q_0}$$

The complete annual cost is then

$$Y = \frac{C_6 q}{p^e} + C_7 pq$$

Differentiating $Y$ with respect to $p$ and equating to zero, we have for a minimum

$$\frac{dY}{dp} = -\frac{eC_6 q}{p^{e+1}} + C_7 q = 0$$

or

$$p_m = \left(\frac{eC_6}{C_7}\right)^{\frac{1}{e+1}}$$

Taking the value of $e$ determined in Equation [14], $e = 0.438$, $\dfrac{1}{e+1} = 0.695$, and

$$p_m = 0.564 \left(\frac{C_6}{C_7}\right)^{0.695} \ldots\ldots\ldots\ldots\ldots [22]$$

In many cases it is desirable to know the effect of adding to the length of an exchanger or to know how much to add to secure certain temperatures. For this, the simpler equation, eliminating $p$, is more convenient. This applies to either liquids or gases:

$$L = \frac{26.8}{C_2} W^{1/6} \frac{\Delta}{\Theta} F^{-1/3} d^{5/6} \left(\frac{C_p}{k}\right)^{2/3} \ldots\ldots\ldots [23]$$

The temperature relation $\Delta/0$ is directly proportional to $L$ and is not greatly affected by moderate changes in the flow rate.

In general, Equation [1] seems to rest on a sound basis. The value of $C_1$ obtained from Rice (48 tests by Soenneken, Stanton

Clement and Garland, Pannel and Jordon) 53.5; from McAdams and Frost (63 tests by Clement and Garland, Wishnew, Trowbridge, Webster, Barton and Safford, and Voss) 54.0; from Babcock and Wilcox, 53.1; from oil tests collected by the writer, 51.8; all tend to confirm the general accuracy of the exponents $\alpha$ and $\beta$ under a wide range of conditions. However, the value of $C_1$ (53.5) is only accurate as a general average. Minor variations in $C_1$ in each group of cases are still to be explained. It is quite possible that $C_1$ will be found to vary with some other dimensionless combination, such as $\mu_1/\mu_2$ or $\mu_3/\mu_4$, where $\mu_3$ and $\mu_4$ apply to inlet and outlet temperatures, or $L/d$. Other combinations which have not been tried are $V^2/(2g)L$, $LvGC_p/K$ and $WC_p/Pk$.

## NOMENCLATURE

$A$ = inside surface of exchanger, sq. ft.
$a$ = inside cross-section of exchanger, sq. in.
$C$ = coefficient in general
$C_1$ = coefficient in Nusselt-Rice equation
$C_2$ = ratio of one film transfer rate to overall transfer rate, $U/h$
$C_p$ = specific heat at constant pressure
$d$ = inside diameter of tube, in.
$d_e$ = effective diameter = $4a/P$
$e$ = exponent of $p = \alpha/(3 - \alpha - \gamma)$
$F$ = fluidity = $1/\mu$
$f$ = coefficient of fluid friction
$G$ = specific gravity compared to water
$H$ = total heat transmitted, B.t.u. per hour
$h$ = heat transfer rate for one fluid film, B.t.u. per sq. ft. per deg. per hr.
$k$ = thermal conductivity, B.t.u. per ft. cube per deg. per hr.
$k_0$ = Rice's coefficient (c.g.s. units)
$L$ = length of path in exchanger, ft.
$P$ = perimeter of wetted surface, in.
$p$ = pressure drop, lb. per sq. in.
$q$ = flow rate, g.p.m.
$R$ = thermal resistance of fluid film = $1000/h$
$t_1$ = mean temperature of fluid
$t_2$ = mean temperature of tube wall
$U$ = overall heat-transfer rate, B.t.u. per sq. ft. per deg. per hr.
$v$ = velocity of fluid, ft. per sec.
$W$ = flow rate, lb. per hr.
$Y$ = annual charge
$\alpha$ = exponent of $dvG/\mu$ in Nusselt-Rice equation = (approximately) $^4/_5$
$\beta$ = exponent of $\dfrac{\mu C_p}{K}$ in Nusselt-Rice equation = (approximately) $^1/_3$
$\gamma$ = exponent of $dvG/\mu$ in $f = C(\mu/dvG)$ = (approximately) 0.264 for liquids ($dvG/\mu$ between 40 and 400) and 0.162 for gases ($dvG/\mu$ between 400 and 4000)
$\Delta$ = temperature range of fluid
$\Theta$ = mean temperature difference between hot and cold fluids, or between tube wall and fluid
$\mu$ = viscosity in poises.

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# Discussion

Lawford H. Fry.[9] The paper may be of interest to physicists but it does not present its final conclusions, if any, in a form which will bring much comfort to the practising engineer who, having a given rate of flow of fluid through a tube and knowing the entering temperature, wishes to determine the total amount of heat transferred between fluid and tube over a given tube length, or, which is the same thing, wishes to know the temperature of the fluid leaving the tube.

Equation [1] for heat transfer per square foot per hour involves specific gravity, conductivity, viscosity, and specific heat at pressure. It would be of considerable assistance in checking the author's work against other experimental data, if he gave the values he uses for these four properties of the fluids with which he is concerned. These values vary with the temperature of the fluid and must therefore vary as the temperature of the fluid drops in flowing along the wall. It therefore appears that in Equation [23] which is intended to apply to a flue of material length $L$ some statement should be made as to how the values of the properties of the fluid should be averaged so as to give mean values applicable to the length $L$.

The Hedrick-Fessenden type of formula[10] which deals with the drop of temperature along a flue instead of attempting to arrive at the coefficient of heat transfer for an element of the flue surface, seems to be much better adapted to engineering use. The present writer has shown[11] that with this type of formula it is possible to find coefficients which are applicable to a wide range of practical conditions. In the writer's work coefficients were determined empirically, but their rather wide usefulness indicates that their structure probably corresponds somewhat closely to the theoretical requirements.

If Mr. Cox intends his work to be of practical value to others, it is hoped that he will supplement the information in his paper by the information necessary to enable the results of the formulas to be measured against experimental data.

W. H. McAdams.[12] The attempt of the author to clarify the complicated and exceedingly important problem of heat transmission for turbulent motion, particularly in the case of viscous liquids, by the use of the Nusselt formula (his Equation [1]), is a step in the right direction. It is unfortunate that he did not have available the work of Whitman and Morris, presented last September at the meeting of the American Chemical Society in Detroit, but which has not yet appeared in the journal.[13] Whitman, like Cox, reduced Rice's value of $\beta$, using 0.37 instead of Cox's value of 0.33. Whitman made 106 runs in heating and cooling three different oils, and 12 runs on water, and furthermore he actually measured pipe-wall temperatures and experimentally determined the viscosity-temperature curve of the various oils. In terms of the Nusselt coefficient $C_1$, Whitman's results are of

[9] Standard Steel Works Co., Burnham, Pa. Mem. A.S.M.E.

[10] "On the Transmission of Heat in Boilers," by E. R. Hedrick and E. A. Fessenden, *Journal*, A.S.M.E., vol. 38, August, 1916, p. 619.

[11] "The Transfer of Heat between a Flowing Gas and a Containing Flue," by Lawford H. Fry, *Journal*, A.S.M.E., vol. 39, October, 1917, p. 843.

[12] Professor, Department of Chemical Engineering, Mass. Inst. of Technology, Cambridge, Mass. Mem. A.S.M.E.

[13] Since the above discussion was presented, the paper of Morris and Whitman has appeared, *Jl. Industrial and Engineering Chemistry*, vol. 20, no. 3, March, 1928, p. 234.

the same order of magnitude as Cox's. Furthermore, Whitman emphasizes the fact that the method of averaging the viscosity, to be employed in the Nusselt formula, profoundly affects the correlation of data. When employing film viscosities, Whitman found that the coefficient $C_1$ is approximately twice as much for cooling as for heating, but when viscosity at the bulk temperature was used the value of $C_1$ for cooling was 0.75 times that for heating. He therefore adopted the latter method.[14]

Therefore, the method of averaging to be employed in determining film viscosity is subject to discussion. It is unfortunate that Mr. Cox does not give viscosity-temperature curves which he used for his oil, so that his data can be compared with the results of Whitman and other investigators, by methods of averaging the values of $\mu$ other than his own.

From the article one gathers the impression that its author is inclined to present the Nusselt equation as a general equation for heat transmission between pipe walls and fluids in turbulent motion. If this is the purpose, it is desirable that the equation be tested on at least a large portion of the other data available in the literature. Thus, there seems no reason apparent on the face of the record for discarding the data on heat transmission of Fessenden and Haney[15] in favor of the Babcock & Wilcox results. Furthermore, adequate correction should be made for gas radiation[16] which was not negligible at the higher temperatures employed by Babcock & Wilcox. It seems doubtful whether we are yet in a position to set up a truly general equation for heat transmission in this case.

In the opinion of the writer, it is safer, in the present state of our knowledge, to use the Nusselt equation for correlation of data by plotting logarithmically the dimensionless group $hd/k$ against $DvG/\mu$, using a separate curve for each type of fluid. Where possible, one should plot separately the data for each fixed value of the group $\mu c/k$. The intercepts[17] of the various curves thus obtained will give the influence of this group on the Nusselt coefficient $C_1(\mu c/k)$. This variation in $C_1(\mu c/k)$ may then be treated graphically or algebraically. Where this amount of data is not available, a single plot for a given fluid or fluid type may be constructed, in which each experimental point has indicated on it its corresponding value of the group $\mu c/k$. Points corresponding to equal values of this axis may then be connected; where minor variations in this axis exist it is usually possible to correct for such variations by inspection. This method of correlation of data is exceedingly helpful and is probably the safest one to employ until we are surer than at present of such matters as the true influence of $\mu c/k$ axis, the proper way to average viscosities, the possible influence of other variables, the absolute values of thermal conductivities of liquids, and the influence of temperature thereon, and the like.

With reference to the author's method of determining optimum conditions of operation of heat-exchange equipment from the point of view of economic balance, it would be well to point out wherein his method differs from that of Lewis, Ward, and Voss,[18] except for the correction for length over diameter made by them and for slight variations in the numerical values of the constants. It would be interesting to know how the results of the two methods of design compare in specific illustrative cases.

[14] Whitman states that a still better correlation was possible b employing $\mu$ corresponding to a temperature "at a point one-fourth the thickness of the film from the main stream." Since this method would require trial-and-error work on the part of the designer, Whitman decided to employ bulk viscosity, allowing for the fact that $C_1$ for cooling was 75 per cent of $C_1$ for heating.

[15] The University of Missouri Bulletin No. 26, October, 1916.

[16] "Heat Transmission by Radiation from Non-Luminous Flames," by H. C. Hottell, *Ind. & Eng. Chem.*, Aug., 1927, vol. 19, no. 8, p. 888.

[17] That is, the ordinates corresponding to $DvG/\mu$ = unity.

[18] *Ind. & Eng. Chem.*, vol. 16, 1924, p. 467.

The author fails to emphasize the point that uncertainties in $C_1$ and $\beta$ have very little effect on the determination of the optimum conditions of operation. Most fortunately, from the engineering point of view, the proper operating conditions can be predicted with a precision far greater than would be anticipated in view of the variations encountered in the direct use of the Nusselt equation.

Willis H. Carrier.[19] The important contribution that the author has made in this paper is that he has shown the application of the rationalized Osborne Reynolds formula through a very wide range of densities and viscosities both for liquids and gases, and has substantiated this in several important cases by experimental data. Similar investigations have been made by others whom he mentions, particularly Rice and McAdams. He is able to use the same type of formula for gases with densities varying as widely as that of hydrogen and chlorine and also for liquids having viscosities varying from that of water to heavy oils, for the latter of which he gives some new and interesting data. It is by this experimental study of the extremes in density, viscosity, and specific heat that he is able to determine with a considerable degree of accuracy the law of these variations in their relation to heat transfer, and for this reason the paper has a great deal of interest to the engineer or physicist who is making a research on the general laws of heat transfer.

The author also makes some very useful and practical suggestions as to the design of surface for the greatest overall economy depending upon the nature of the fluid handled.

D. R. Harper.[20] This paper is a much needed contribution in the line of making more readily available for engineering application, that vast storehouse of general scientific work which has been done on the subject of heat transfer. The excellent illustration of general principles the author has given, in bringing together experiments over a wide range of viscosities, should increase the confidence of engineers in these relations. The paper contains little which is an actual contribution to the fundamental literature in this field, but it does translate into British units much which has not been so well known to date as it should be, partly because of its places of publication, partly because of nomenclature and units unfamiliar to mechanical and refrigerating engineers.

W. Trinks.[21] This is a most valuable paper. Nowhere in it, however, is anything said about radiation. Those of us who have wrestled with oil stills know only too well that the gases which touch the oil still on one side radiate their heat to the tubes and that, therefore, we cannot separate radiation in oil-still work. I believe, coming from California, and being in the gasoline business, Mr. Cox may be interested in oil stills. We should never forget that radiation influences the gas side, at least.

R. J. S. Pigott.[22] This paper is an important contribution for the following reasons:

As is well known there are variations in heat transfer in condensers from possibly 200 B.t.u. under cold-water conditions and poor air removal, up to as high as 800 or 900 B.t.u. under conditions of warm condenser water, minimum air leakage, and proper design of the condenser.

In the feedwater-heater group, there are variations from 300 to as high as 1800 B.t.u. Nobody seems to know definitely

[19] Carrier Engineering Corp., Newark, N. J. Mem. A.S.M.E.

[20] General Electric Company, Schenectady, N. Y.

[21] Professor, Mechanical Engineering, Carnegie Institute of Technology, Pittsburgh, Pa. Mem. A.S.M.E.

[22] Cons. Engr., Public Service Prod. Co., Newark, N. J. Mem. A.S.M.E.

what the heat transfer coefficient ought to be. In the case of oil coolers values are even less definite. Of course, $\mu/\rho$ is kinematic viscosity and the quantity $ds\rho/\mu$ indicates the effect of diameter (which is the size factor) times the speed of the fluid, divided by kinematic viscosity. One thing is quite evident; that is, nobody has paid much attention to the viscosity of the fluids as yet. That is the one remaining factor which is the reason why there have been no concordant results. It just so happened without knowing anything about this paper that I started some of my staff working out test results. We found in the first check plots that water-heater and condenser tests can be plotted largely on a single line if the viscosity of the fluid is taken into account. That is on the assumption that the controlling resistance is on the water side of the transfer apparatus. Under conditions of very large air leakage in the steam and cold water, the resistance may be on the steam side, but ordinarily there is not much air dilution. We do not know quantitatively just what effect dilution of the steam with air has on transfer. That is the next thing to be investigated after we check up the liquid side. There is no question that our calculations all the way down to actual purchase will be tremendously affected by getting consistent line-up of B.t.u. transfer coefficients on a basis of this sort. Too few people have been regarding the Reynolds number as being of value in the design of heat-transfer apparatus.

The Author. The paper deals solely with heat transfer by conduction, as affected by forced convection.

Radiation was not dealt with as it is properly a separate subject. However, it may be said in this connection that the author has been able to check boiler tests quite closely by deducting the radiation from the total heat generated and assuming that the remainder determines the furnace temperature. This is in accordance with the old saying, "We cannot eat our cake and have it." Since radiation is instantaneous and combustion requires an appreciable, although very minute, interval of time, heat radiated cannot appear as sensible heat of the gases. If it did we would have accounted for more than the total heat generated. It has often been noted that furnace temperatures as measured never quite reach the calculated. If the deduction is made for radiation in this manner, the results will check quite closely. Since the radiation depends upon the furnace temperature, this cannot be calculated directly, but may be determined by trial and error or by plotting a curve. No doubt there is some radiation beyond the furnace proper, but this is small compared with the heat conducted.

Mr. Fry questions the convenience of this formula for determining the final temperatures, given the initial, flow rates, and other conditions of a given exchanger.

This is a special case and by no means as simple as the conventional problem which is merely to determine the amount of surface, size and length of tubes, and number in multiple, necessary to affect a given heat exchange. The properties of the fluids are determined by taking the mean between the inlet and outlet temperatures, then the mean between this temperature and that of the tube wall. The final mean determines the fluid properties. In the case of viscosities which vary greatly, a preferred method is described in the text. To solve Mr. Fry's problem it would be necessary to resort to the method of trial and error. He suggests the Hedrick-Fessenden type of formula as better adapted to a problem of this sort. As the author recalls it, this is of the form $T_1/T_2 = (T_3/T_4)^{\alpha}$ where $\log \alpha = Mx$, $M$ being an empirical constant and $x$ the length. Several years ago the writer endeavored to check by means of this formula some tests upon an oil to oil exchanger in which a number of intermediate temperatures had been obtained. Determining $\alpha$ from the four end temperatures and calculating intermediate values these did not check well with the observed values. Curiously enough, when fluidities were substituted for temperatures, the check was quite close. The fluids were crude oil and residuum, where viscosity plays a very important role. It is possible that a formula of this type might be quite useful in determining intermediate temperatures and in extrapolating for additional length. Whether it would be practical for exchanger design, the writer is not prepared to form an opinion. It might prove to be as difficult to determine the coefficient $M$ for different fluids and flow rates, as to calculate $U$.

Mr. Pigott also brings up an important special problem, namely that of condensing vapors. Here the conductance depends mainly upon a film of condensate clinging to the tube wall. As it is impossible to determine the velocity of this film, the subject cannot be treated by the above formula. McAdams and Frost found that the conductance depended upon both the conductivity and viscosity of this film. In the case of steam condensers, the problem is still further complicated by the presence of air. For this case Orrok's empirical formula[23] is probably the most reliable. In condensing gasoline, particularly natural gasoline, a large amount of non-condensible gases greatly affects the rate. Very little work has been done on determining this effect.

The author fully agrees with Professor McAdams that more work should be done on investigating the effect of viscosity and how it should be averaged. The author did not publish the chart by which the viscosities used in Tables 2 and 3 were obtained because it was not believed that these tests were sufficiently reliable to justify any but the most general conclusions. It is well known among oil men that oils of the same gravity from different fields may have quite different viscosities. This applies even to oils from different wells in the same district. The author also plotted the tests in Tables 2 and 3 using body viscosities, and obtained not only different curves for heating and cooling, but greatly differing curves for heating light and heavy oils. This would necessitate two complete families of curves, involving an elaborate series of tests, and would be wholly empirical. Hence it would not indicate a general law for forced convection. In regard to the Babcock & Wilcox tests, one cannot read the description of these tests without being impressed by the comprehensive nature and range of the tests and the elaborate precautions taken to insure accuracy. To question them would require a rather overwhelming burden of proof.

As to radiation, Ray and Kreisinger[24] found that in a Heine boiler the ratio of heat radiated to that conducted was from 3 to 15 per cent. If we allow for the radiation in the furnace proper, this 3 to 15 per cent is practically covered and the remainder of the heat transmitted may be safely assumed to comply with the Nusselt-Rice equation.

It has by no means been the idea of the author that the subject was finished and the book closed. On the contrary the purpose of the paper has been mainly to collect and correlate the progress so far made and to prove, if possible, that this rests upon a solid foundation. If this has been accomplished, further progress, which is inevitable, will be rather in the line of refinements making for greater accuracy.

[23] *Transactions*, A.S.M.E., vol. 32, 1910, p. 1139.

[24] L. P. Breckenridge, "Study of Four Hundred Steaming Tests," U.S. Geol. Survey, 1907.

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# The Gas Lift as Applied to Oil Production

## Description of the Central-Plant System—Results of the Gas-Lift Process—Factors in Operation—Limitations of the Process

By F. W. LAKE,[1] BREA, CALIF.

The gas lift, as a method of producing oil, has reached a high state of development, and its application has been widespread during the last two years. In theory and practice it is similar to the operation of natural flowing wells. It is a development of the air-lift method of raising water, applied under different conditions and hence necessitating a different set of principles and methods of operation. This is due not only to the differences in the physical characteristics of air and water and gas and oil, but also to the essential objectives of the two operations. Water air lifts are designed for the delivery of a quantity of water in such a manner that the power efficiency is as high as possible and hence the cost of lifting near to or less than that incurred by mechanical pumping. Oil gas lifts are designed not for a high power efficiency but for obtaining the maximum net income from a producing property. For 25 years previous to recent developments, the gas lift had been attempted infrequently, but with few satisfactory results which could not be duplicated. Recent experimental work, however, has been conducted in such a manner that the underlying principles have been discovered and the process can now be applied with precision.

### The Central-Plant System

As usually applied in the most efficient systems, dry gas is compressed to the required pressure at central compressor

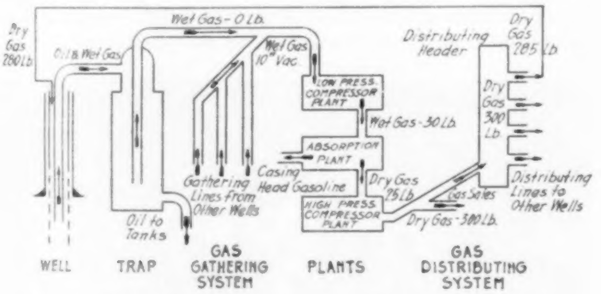


Fig. 1 Flow Diagram, Gas-Lift Central-Plant System

plants and is then pumped to a centrally located distributing header or manifold. If certain wells require pressures widely different from the majority, these should be taken into consideration in designing the compressor plant so that a certain volume at one pressure may be pumped to the main distributing header, while a different volume at a different pressure can be pumped to distributing headers serving the odd wells separately. From the distributing header, individual lines are run to each well, and by the application of meters and valves on each line the required volume of gas can be continuously delivered to each well on the system from the central point. The gas is usually introduced into the casing head between the casing and tubing, and is pumped down to the bottom of the tubing. As it enters the tubing it mixes with the oil to a certain extent and is also dissolved in the oil. No mixing device, flow piece, or jet is necessary. Usually a few perforations are drilled in the tubing a few feet from the bottom to allow the gas to enter the tubing through an opening separate from the oil opening without causing any unnecessary back pressure. The oil-gas mixture rises in the tubing, similar to natural flowing conditions, and enters the trap or separator. Here the oil and gas are separated, the oil flowing to the flow tanks and the gas entering the gathering system.

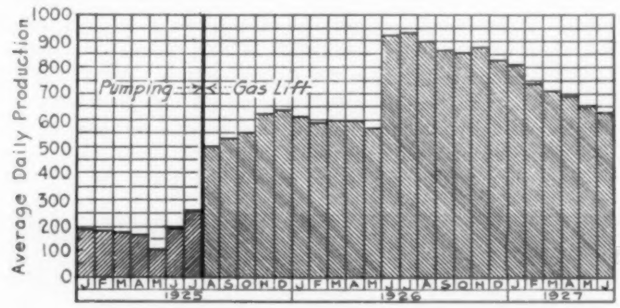


Fig. 2 Production-Decline Curve, Brooks No. 2 Well, Huntington Beach Field, Union Oil Co. of California

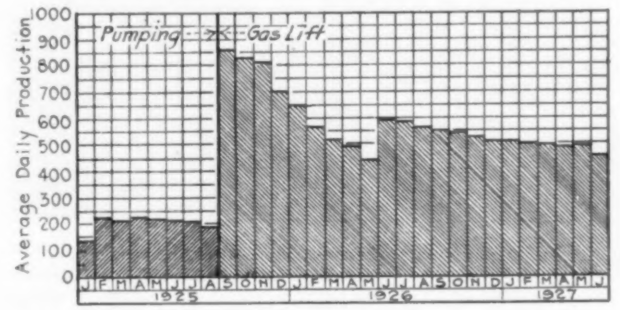


Fig. 3 Production-Decline Curve, Chapman No. 6 Well, Richfield Field, Union Oil Co. of California

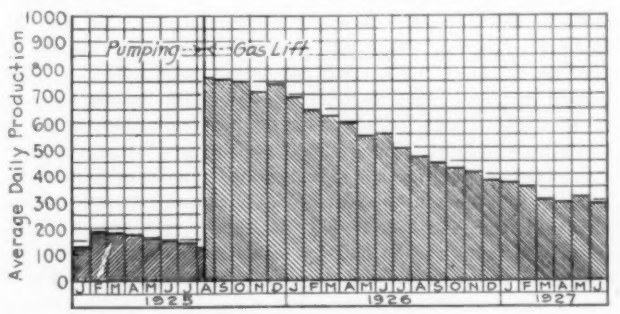


Fig. 4 Production-Decline Curve, Morse No. 3 Well, Richfield Field, Union Oil Co. of California

Through the gathering system, the gas is pulled in from the various wells by a compressor plant and is delivered to an absorption plant where the gasoline content is removed. The dry gas is then delivered to the gas-lift compressor plant, the excess being sold or used as fuel on the lease. The gas-lift system is thus a closed circuit, the gas being alternately compressed and ex-

[1] Superintendent of Production, Union Oil Co. of Calif.

Presented at the Seattle Meeting, Seattle, Wash., August 29 to 31, 1927, of The American Society of Mechanical Engineers, 29 West 39th St., New York, N. Y.

panded as it does the work of lifting the oil. Fig. 1 is a flow diagram of the gas-lift central-plant system.

In the event of a leaky casing or low-pressure sands, the process can be reversed and the gas pumped down the tubing, the oil-gas mixture then flowing up between the casing and tubing. This practice is not advisable unless conditions necessitate its use, as it is usually low in efficiency and does not give the maximum results possible.

### Results of the Gas-Lift Process

One of the results of the application of the gas lift to oil production is the increased daily rate of production. This increase may vary from a small percentage to as high as several hundred per cent. Fig. 2 shows a production-decline curve of the Union Oil Company's Brooks Well No. 2 in the Huntington Beach Field. This well was completed at a depth of 4545 ft. in November, 1922, with an initial production of 2000 barrels of oil daily. It had declined to less than 200 barrels daily in the first half of 1925. The first gas-lift installation raised the production to 600 barrels daily for nine months. At this time a change in the operation was made with the result that the production increased to more than 900 barrels daily, from which point the well has

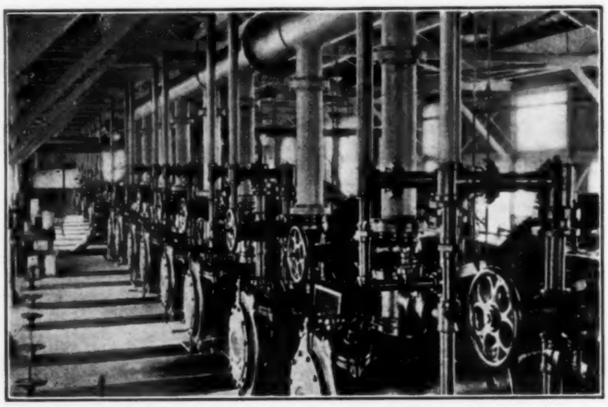

Fig. 5 Typical Compressor Plant, Compressor End

(Nine compressors direct connected to 165-hp. gas engines are employed. Five are used to pull in the gas from the field as low-pressure compressors operating from 10 in. vacuum to 30 lb. gage, and four are used as high-pressure compressors boosting the gas to pressures of from 25 to 200 lb. per sq. in. for gas-lift operations.)

had a gradual decline to the present. Fig. 3 shows a similar curve on the Union Oil Company's Chapman Well No. 6 in the Richfield District. This well was completed at a depth of 4147 ft. in May, 1921, with an initial production of 2100 barrels daily. It had declined to about 200 barrels daily in the first half of 1925. The gas-lift method raised the production to 850 barrels daily. The decline was more rapid than necessary, due to the original method of operation. In June, 1926, when a change was made in the adjustment of the well, the production increased from 440 barrels daily to almost 600 barrels daily. From this point the decline has been commensurate with the decline in reservoir pressure, which is to be expected. Fig. 4 shows the production-decline curve of the Union Oil Company's Morse Well No. 3 in the Richfield District. This well was completed at a depth of 4340 ft. in April, 1922, with an initial production of 4300 barrels daily. It had declined to an average of 150 barrels in the first part of 1925. The installation of the gas-lift process raised the production to more than 750 barrels daily, from which point the well has had a slow decline to the present. These curves illustrate a few of the increases in the rate of production which are possible in certain instances by the proper installation of the gas-lift process. More important but not quite as apparent is the increased ultimate production resulting from the gas-lift process. Since gas is recognized as one of the essential factors in bringing the oil from the sand interstices to the well, it follows that any decrease in the ratio of formation gas produced per barrel of oil will result in a corresponding increase in the ultimate recovery from the well. The application of the gas-lift process usually results in a lower gas-oil ratio, the extent of which depends on the efficiency of the former production method. For an average of the results so far obtained, it seems that the gas-oil ratio can be reduced at least 25 per cent. An additional factor tending to increase the

Fig. 6 Typical Distributing Header Handling 25 Gas-Lift Wells

ultimate recovery from a well is the elimination of all moving equipment from the hole. This reduces the liability of parted tubing and the resulting fishing jobs which more than once have meant complete abandonment of the hole. The increased daily rate of production tends toward an increase in ultimate recovery

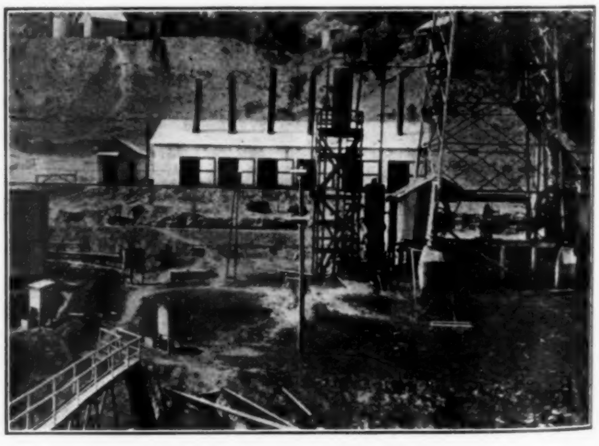

Fig. 7 Typical Connections and Relative Locations of Well, Trap, and Tanks for Gas-Lift Hook-Up

as a more rapid delivery of oil is effected, with an equal or less hazard of collapsed or deteriorated casing.

Under proper application of the gas-lift process, a greater net return is possible. This is due not only to production increases but also to other conditions resulting from the process. The central power system results in lower operating costs, particularly from a labor-saving standpoint. The elimination of individual power plants and the power centralization permits better care of machinery, with subsequent decreases in repair and maintenance costs. With no pumping equipment in the hole, the necessity

for well-pulling labor is almost eliminated. In addition to these factors, the increased rate of production means a more rapid return on the investment in a property. As a result of the application of the gas-lift process, the net income from a property should be appreciably increased and should be realized in a shorter period of time.

### Factors in Operation

The control of the process lies in the tubing diameter and depth, the gas volume circulated, and the pressure held back on the producing sand, which latter varies with these factors and also with the tubing-head pressure. Oil and gas exist under pressure in the interstices of the producing horizon, and the rate of extraction is inversely proportional to the existing back pressure in the hole opposite the producing horizon. Hence for the maximum daily production the effective back pressure should be a minimum opposite the most productive portion of the producing horizon. The effective back pressure at the bottom of the tubing is equal to the sum of (1) the tubing-head pressure, (2) the pressure drop due to friction of the oil-gas mixture in flowing from the bottom of the tubing to the top, and (3) the pressure due to the difference in elevation of the bottom and top of the tubing with the static head of the oil-gas column. Where there are no appreciable losses of gas due to casing leaks or low-pressure sands, the effective back pressure at the bottom of the tubing is also equal to (4) the casing-head pressure, less (5) the pressure drop due to friction of the gas flowing down the annular space between the casing and tubing from the surface to the bottom of the tubing, and plus (6) the static head of the gas between the casing and tubing. If the tubing extends lower than the top of the producing horizon, items (5) and (6) are influenced by the amount of oil entering the well above the bottom of the tubing and moving down with the gas to the lower end of the tubing. Thus the minimum back pressure occurs at the bottom of the tubing.

The most efficient tubing diameter is dependent on two factors, namely, friction and slippage. Friction is inversely proportional to the tubing diameter, while slippage is directly proportional to the tubing diameter. For maximum results, that diameter should be used which will give the minimum friction with the minimum slippage, consideration being given to the relative volumes of oil and gas to be handled and their respective physical properties.

With respect to the tubing-head pressure, all connections, the trap setting, the tank location, and the trap pressure should be such that the minimum tubing-head pressure is obtained. Pressure drop due to friction should be reduced to a minimum. Trap and tank locations should be so arranged that gravity flow is possible. Trap pressures should be reduced to as near atmospheric pressure as possible. The relation between a low tubing-head pressure and the minimum back pressure is evident, and proper attention to these details will result in more efficient gas-lift operation.

The volume of gas circulated should be controlled so that the minimum steady pressure is obtained. Lack of gas causes heading or surging with the average back pressure higher than necessary. Too much gas, although the pressures are steady, crowds the system with gas and results in a higher back pressure than necessary with a corresponding decrease in production.

Thus tubing-head pressure, tubing diameter and depth, and the gas volume circulated are the factors permitting adjustment and upon which the efficiency and results of the gas-lift process are dependent.

### Limitations of the Gas-Lift Process

While exceptional results are possible from a proper application of the gas-lift process in certain instances, still it is not without definite limitations. Where water in sufficient quantities is produced with oil of such physical characteristics that tight emulsions tend to be formed, gas lift may not be economical, due to the high cost of treating the emulsion. This limitation is dependent on the physical properties of the oil and relative quantities of oil and water produced. Under some conditions, the advantages resulting from gas lift may be more important than the disadvantages resulting from the formation of emulsions. This is an economic problem peculiar to local conditions.

In areas of low rock pressure the continuous gas-lift system may not be economical. If the minimum pressure for continuous gas-lift operation causes a back pressure on the producing formations in excess of that which exists by reason of the fluid head in the hole during pumping operations, the production by gas lift will be less than that produced by pumping. Intermittent gas lift, where the fluid is blown out of the hole at periodic intervals, may be applied and some of the advantages of the continuous gas-lift system obtained. Experimental work is now being carried on for the development of a stage gas lift which will reduce emulsion difficulties and prove more efficient than the intermittent gas-lift system, particularly in application to production from low-pressure horizons.

# The Degree-Day Method of Fuel-Consumption Analysis

## Its Application to Fuel Deliveries for Domestic Oil Burners

By W. R. Abbott,[1] Louisville, Ky.

The circumstances leading up to this particular application of the degree-day method of fuel consumption analysis are as follows:

The company with which the author is associated is engaged in the refining and marketing of various petroleum products and one of its problems is the creation of a local fuel-oil market and the subsequent permanent retention of the business so developed.

The first step was to engage in the sale, installation, and servicing of oil burners with particular attention to fully automatic domestic equipment.

After a survey has been made of the existing or proposed heating equipment we recommend (in the event conversion to oil is justified) such tankage, oil burners, control equipment, etc., as the company has found from its experience to be most suitable. This recommendation is made in the form of a definite proposal covering a completed job at a lump-sum price. The company guarantees complete satisfaction as to capacity of equipment installed, automatic operation, and dependability. Night-and-day service is available, and in the event the customer chooses to purchase his fuel oil from the company, this service is without charge. The company obtains customers' permission to deliver fuel when and as needed, and assumes full responsibility for the prevention of "empty tankage" service calls.

The result, from the customer's point of view, is that he is actually purchasing automatic heat as free from care on his part as is his electric light, telephone, gas, or water service. The result, from the company's point of view, is that it develops a tank-wagon fuel-oil business which is of a more permanent nature than that of the average petroleum product marketed, and does so with a minimum of direct sales effort.

The company first applied the degree-day method of fuel consumption analysis to the invesigation of complaints as to excessive fuel costs. Later it was used in checking up the results obtained from various changes made to original installations for the purpose of lowering fuel costs. Then it was applied to checking efficiencies of oil-fired heating plants, and lastly to the subject under discussion, fuel-oil deliveries.

The ideal in tank-truck delivery is:

1 Full tank-truck dumps
2 Complete freedom from idle or stand-by time
3 Continuous operation of rolling equipment.

It is necessary to know, therefore, exactly when a tank is down to the point that it will permit a full tank-truck dump, and it is necessary to know when it will be empty if the delivery is not made. The interval between these two is the company's delivery margin as to time.

The company's procedure to obtain this information without periodically gaging each and every tank is as follows:

The daily mean temperature is obtained from the United States Weather Bureau and what is termed a "Degree-Day Log," Fig. 1, is compiled from this information.

Column 1 is the date.

Column 2 is the mean temperature in degrees fahrenheit.

Column 3 is difference between this mean temperature and 70 deg., and represents in degree-days the heating load for this particular day. The term "degree-day" is, as its name implies, the product of two quantities, temperature and time—one degree fahrenheit and one twenty-four-hour day. We assume 70 deg. as

| DATE | MEAN TEMP | DEG-DAYS | TOTAL TO DATE | DATE | MEAN TEMP | DEG-DAYS | TOTAL TO DATE | DATE | MEAN TEMP | DEG-DAYS | TOTAL TO DATE | DATE | MEAN TEMP | DEG-DAYS | TOTAL TO DATE | DATE | MEAN TEMP | DEG-DAYS | TOTAL TO DATE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SEPTEMBER-1927 | | | | NOVEMBER-1927 | | | | DECEMBER-1927 | | | | FEBRUARY-1928 | | | | | | | |
| 18 | 74 | -4 | 0 | 6 | 34 | 36 | 467 | 26 | 30 | 40 | 1848 | 13 | 40 | 30 | 3477 | | | | |
| 19 | 63 | 7 | 7 | 7 | 35 | 35 | 502 | 27 | 38 | 32 | 1880 | 14 | 41 | 29 | 3506 | | | | |
| 20 | 58 | 12 | 19 | 8 | 38 | 32 | 534 | 28 | 44 | 26 | 1906 | 15 | 37 | 33 | 3539 | | | | |
| 21 | 54 | 16 | 35 | 9 | 42 | 28 | 562 | 29 | 55 | 15 | 1921 | 16 | 38 | 32 | 3591 | | | | |
| 22 | 56 | 14 | 49 | 10 | 56 | 14 | 576 | 30 | 56 | 14 | 1935 | 17 | 34 | 36 | 3607 | | | | |
| 23 | 59 | 11 | 60 | 11 | 70 | 0 | 576 | 31 | 32 | 38 | 1973 | 18 | 18 | 52 | 3659 | | | | |
| 24 | 67 | 3 | 63 | 12 | 46 | 24 | 600 | JANUARY-1928 | | | | 19 | 22 | 48 | 3707 | | | | |
| 25 | 67 | 3 | 66 | 13 | 46 | 24 | 634 | 1 | 2 | 68 | 2061 | 20 | 30 | 40 | 3747 | | | | |
| 26 | 70 | 0 | 66 | 14 | 66 | 4 | 628 | 2 | 6 | 64 | 2125 | 21 | 29 | 41 | 3788 | | | | |
| 27 | 74 | -4 | 66 | 15 | 60 | 10 | 638 | 3 | 10 | 60 | 2185 | 22 | 37 | 33 | 3821 | | | | |
| 28 | 69 | 1 | 67 | 16 | 49 | 21 | 659 | 4 | 18 | 52 | 2237 | 23 | 42 | 28 | 3849 | | | | |
| 29 | 72 | -2 | 67 | 17 | 35 | 35 | 694 | 5 | 28 | 42 | 2279 | 24 | 22 | 48 | 3897 | | | | |
| 30 | 72 | -2 | 67 | 18 | 32 | 38 | 732 | 6 | 42 | 28 | 2307 | 25 | 23 | 47 | 3944 | | | | |
| OCTOBER-1927 | | | | 19 | 32 | 38 | 770 | 7 | 43 | 27 | 2334 | 26 | 24 | 46 | 3990 | | | | |
| 1 | 78 | -8 | 67 | 20 | 39 | 31 | 801 | 8 | 41 | 29 | 2363 | 27 | 38 | 32 | 4022 | | | | |
| 2 | 77 | -7 | 67 | 21 | 54 | 16 | 817 | 9 | 35 | 35 | 2398 | 28 | 42 | 28 | 4050 | | | | |
| 3 | 70 | 0 | 67 | 22 | 61 | 9 | 826 | 10 | 43 | 27 | 2425 | 29 | 40 | 30 | 4080 | | | | |
| 4 | 62 | 8 | 75 | 23 | 61 | 9 | 835 | 11 | 51 | 19 | 2444 | MARCH-1928 | | | | | | | |
| 5 | 64 | 6 | 81 | 24 | 52 | 18 | 853 | 12 | 48 | 22 | 2466 | 1 | 21 | 49 | 4129 | | | | |
| 6 | 70 | 0 | 81 | 25 | 46 | 24 | 877 | 13 | 55 | 15 | 2481 | 2 | 41 | 29 | 4162 | | | | |
| 7 | 64 | 6 | 87 | 26 | 58 | 12 | 889 | 14 | 56 | 14 | 2495 | 3 | | | | | | | |
| 8 | 56 | 14 | 101 | 27 | 68 | 2 | 891 | 15 | 53 | 17 | 2512 | 4 | | | | | | | |
| 9 | 57 | 13 | 114 | 28 | 66 | 4 | 895 | 16 | 55 | 15 | 2527 | 5 | | | | | | | |
| 10 | 58 | 12 | 126 | 29 | 65 | 5 | 900 | 17 | 52 | 18 | 2545 | 6 | | | | | | | |
| 11 | 66 | 4 | 130 | 30 | 52 | 18 | 918 | 18 | 44 | 26 | 2571 | 7 | | | | | | | |
| 12 | 61 | 9 | 139 | DECEMBER-1927 | | | | 19 | 50 | 20 | 2591 | 8 | | | | | | | |
| 13 | 49 | 21 | 160 | 1 | 25 | 45 | 963 | 20 | 22 | 48 | 2639 | 9 | | | | | | | |
| 14 | 51 | 19 | 179 | 2 | 36 | 34 | 997 | 21 | 22 | 48 | 2687 | 10 | | | | | | | |
| 15 | 54 | 16 | 195 | 3 | 31 | 39 | 1036 | 22 | 32 | 38 | 2725 | 11 | | | | | | | |
| 16 | 58 | 12 | 207 | 4 | 34 | 36 | 1072 | 23 | 40 | 30 | 2755 | 12 | | | | | | | |
| 17 | 48 | 22 | 229 | 5 | 35 | 35 | 1107 | 24 | 42 | 28 | 2783 | 13 | | | | | | | |
| 18 | 45 | 25 | 254 | 6 | 44 | 26 | 1133 | 25 | 29 | 41 | 2824 | 14 | | | | | | | |
| 19 | 50 | 20 | 274 | 7 | 44 | 26 | 1159 | 26 | 31 | 39 | 26 | 15 | | | | | | | |
| 20 | 60 | 10 | 284 | 8 | 13 | 57 | 1216 | 27 | 25 | 45 | 2908 | 16 | | | | | | | |
| 21 | 60 | 10 | 294 | 9 | 18 | 52 | 1268 | 28 | 11 | 59 | 2967 | 17 | | | | | | | |
| 22 | 64 | 6 | 300 | 10 | 32 | 38 | 1306 | 29 | 20 | 50 | 3017 | 18 | | | | | | | |
| 23 | 71 | -1 | 300 | 11 | 48 | 22 | 1328 | 30 | 24 | 46 | 3063 | 19 | | | | | | | |
| 24 | 64 | 6 | 306 | 12 | 59 | 11 | 1339 | 31 | 28 | 42 | 3105 | 20 | | | | | | | |
| 25 | 64 | 6 | 312 | 13 | 66 | 4 | 1343 | FEBRUARY-1928 | | | | 21 | | | | | | | |
| 26 | 64 | 6 | 318 | 14 | 53 | 17 | 1360 | 1 | 30 | 40 | 3145 | 22 | | | | | | | |
| 27 | 64 | 6 | 324 | 15 | 52 | 18 | 1378 | 2 | 31 | 39 | 3184 | 23 | | | | | | | |
| 28 | 68 | 2 | 326 | 16 | 28 | 42 | 1420 | 3 | 46 | 24 | 3208 | 24 | | | | | | | |
| 29 | 69 | 1 | 327 | 17 | 30 | 40 | 1460 | 4 | 56 | 14 | 3222 | 25 | | | | | | | |
| 30 | 69 | 1 | 328 | 18 | 19 | 51 | 1511 | 5 | 46 | 24 | 3246 | 26 | | | | | | | |
| 31 | 70 | 0 | 328 | 19 | 14 | 56 | 1567 | 6 | 41 | 29 | 3275 | 27 | | | | | | | |
| NOVEMBER-1927 | | | | 20 | 25 | 45 | 1612 | 7 | 52 | 18 | 3293 | 28 | | | | | | | |
| 1 | 55 | 15 | 343 | 21 | 32 | 38 | 1650 | 8 | 44 | 26 | 3319 | 29 | | | | | | | |
| 2 | 56 | 14 | 357 | 22 | 32 | 38 | 1688 | 9 | 36 | 34 | 3353 | 30 | | | | | | | |
| 3 | 48 | 22 | 379 | 23 | 30 | 40 | 1728 | 10 | 34 | 36 | 3389 | 31 | | | | | | | |
| 4 | 48 | 22 | 401 | 24 | 30 | 40 | 1768 | 11 | 42 | 28 | 3417 | APRIL-1928 | | | | | | | |
| 5 | 40 | 30 | 431 | 25 | 30 | 40 | 1808 | 12 | 40 | 30 | 3447 | 1 | | | | | | | |
| 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | | | | |
| U.S. WEATHER BUREAU | | 70-2 | RUNNING TOTAL | U.S. WEATHER BUREAU | | 70-2 | RUNNING TOTAL | U.S. WEATHER BUREAU | | 70-2 | RUNNING TOTAL | U.S. WEATHER BUREAU | | 70-2 | RUNNING TOTAL | | | | |

Fig. 1 Degree-Day Log

the average temperature maintained inside of the building heated.

Column 4 is the total to date of degree-days which have elapsed since the beginning of the heating season.

The entries in the log shown in Fig. 1 submitted herewith are for the heating season of 1927–1928.

It has been found that *within the limits of the Company's requirements* the fuel consumption for a given heating plant is in direct proportion to the elapsed degree-days. A job constant $K$ is therefore obtained by dividing the fuel consumed in gallons on any particular job by the degree-days which have elapsed during the period in question, and this has been found to be a convenient expression of the fuel-consuming characteristics of this installa-

[1] Sales Engineer, Aetna Oil Service Co.

Presented at a meeting of the Metropolitan Section of the A.S.M.E., New York, March 6, 1928.

| INSTALLATION #10 | | ADDRESS #10 | | | TANKAGE 1000 GAL. 48"φ X 10'8" | | | | | | | LOAD: HOT WATER = 1017; EQUIV. STEAM 1017 ÷ 1.42 = 708; EQUIV. UNIT LOAD, C. = 0.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEGREE-DAYS | | | | | GALLONS | | | | | GAL. PER D.D. JOB CONST. | | |
| FROM DATE | FROM DEG. DAYS | TO DATE | TO DEG. DAYS | ELAPSED DEG. DAYS | GAGE 1ST DATE | DELIVERIES | TOTAL | GAGE 2ND DATE | CONSUMPTION | K | K' | |
| 9/13/27 | 0 | 10/31/27 | 339 | 339 | 923 | 0 | 923 | 422 | 501 | 1.48 | 2.08 | High-Notified S.D. 11/1 |
| 10/31 | 339 | 11/8 | 534 | 195 | 422 | 500 | 922 | 870 | 52 | .27 | | Short Period |
| 11/8 | 534 | 12/9 | 1268 | 734 | 870 | 600 | 1470 | 760 | 710 | .97 | 1.37 | High-Notified S.D. 12/10 |
| 12/9 | 1268 | 12/28 | 1906 | 638 | 760 | 700 | 1460 | 850 | 610 | .96 | 1.35 | |
| 12/28 | 1906 | 1/12/28 | 2466 | 560 | 850 | 685 | 1535 | 1000 | 535 | .96 | 1.35 | |
| 1/12/28 | 2466 | 1/28 | 2967 | 501 | 1000 | 200 | 1200 | 712 | 488 | .97 | 1.37 | |
| 1/28 | 2967 | 2/10 | 3402 | 435 | 712 | 468 | 1180 | 819 | 361 | .83 | 1.17 | |
| 2/10 | 3402 | 2/29 | 4088 | 686 | 819 | 375 | 1194 | 651 | 543 | .79 | 1.11 | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | COLUMN NUMBER |
| A-4 | | A-4 | | (2-4) | DELIVERY TICKET | | (6÷7) | DEL. TICKET | (8-9) | (10÷5) | (11÷C) | FROM |

| INSTALLATION #19 | | ADDRESS #19 | | | TANKAGE 2000 GAL. 64"φ X 12'0" | | | | | | | LOAD: STEAM = 983; EQUIV. UNIT LOAD, C = 0.98 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEGREE-DAYS | | | | | GALLONS | | | | | GAL. PER D.D. JOB CONST. | | |
| FROM DATE | FROM DEG. DAYS | TO DATE | TO DEG. DAYS | ELAPSED DEG. DAYS | GAGE 1ST DATE | DELIVERIES | TOTAL | GAGE 2ND DATE | CONSUMPTION | K | K' | |
| 10/1/24 | 0 | 6/1/25 | 5136 | 5136 | 0 | 3130 | 3130 | 18 | 3112 | .61 | .62 | Season 1924-5 |
| 10/1/25 | 0 | 6/1/26 | 6172 | 6172 | 18 | 3900 | 3918 | 132 | 3786 | .62 | .63 | Season 1925-6 |
| 10/1/26 | 0 | 1/13/27 | 2750 | 2750 | 132 | 2713 | 2844 | 1258 | 1586 | .58 | .57 | |
| 1/13/27 | 2750 | 3/22/27 | 4608 | 1858 | 1258 | 250 | 1508 | 324 | 1184 | .64 | .65 | |
| 3/22/27 | 4608 | 9/10/27 | 5240 | 632 | 324 | 1600 | 1924 | 1544 | 380 | .60 | .61 | |
| 6/1/26 | 0 | 9/10/27 | 5240 | 5240 | 132 | 4562 | 4694 | 1544 | 3150 | .60 | .61 | Season 1926-7 |
| 9/10/27 | 0 | 1/2/28 | 2109 | 2109 | 1544 | 700 | 2244 | 914 | 1330 | .63 | .64 | |
| 1/2/28 | 2109 | 3/4/28 | 3235 | 1126 | 914 | 700 | 1614 | 864 | 750 | .67 | .68 | Notified S.O. 2/5/28 |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | COLUMN NUMBER |
| A-4 | | A-4 | | (2-4) | DELIVERY TICKET | | (6÷7) | DEL. TICKET | (8-9) | (10÷5) | (11÷C) | FROM |

Fig. 2 Customer's Card

| DATE 1928 | INSTALLATION | GALS PER DEG-DAY K | GALLONS IN STORAGE | DEGREE-DAYS IN STORAGE | DEGREE-DAYS ELAPSED TO DATE | DEGREE-DAYS EMPTY POINT | GALLONS FILL POINT | DEGREE-DAYS FILL TO EMPTY PERIOD | DEGREE-DAYS FILL POINT | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| Feb. 27 | 118 | 1.0 | 883 | 883 | 4022 | 4905 | 300 | 300 | 4605 | |
| 27 | 94 | 1.5 | 808 | 538 | 4022 | 4560 | 300 | 200 | 4360 | |
| 27 | 67 | 1.5 | 931 | 621 | 4022 | 4643 | 300 | 200 | 4443 | |
| 29 | 85 | 1.4 | 852 | 608 | 4022 | 4630 | 300 | 214 | 4416 | |
| 27 | 189 | 1.0 | 913 | 913 | 4022 | 4935 | 300 | 300 | 4635 | |
| 28 | 25 | 1.0 | 901 | 901 | 4050 | 4951 | 800 | 800 | 4151 | |
| 28 | 31 | 0.9 | 964 | 1071 | 4050 | 5121 | 300 | 333 | 4788 | |
| 28 | 64 | 0.9 | 860 | 855 | 4050 | 5005 | 300 | 333 | 4672 | |
| 28 | 48 | 1.0 | 977 | 477 | 4050 | 5027 | 300 | 300 | 4727 | |
| 28 | 17 | 0.8 | 765 | 956 | 4050 | 5006 | 300 | 375 | 4631 | |
| 28 | 81 | 0.9 | 647 | 718 | 4050 | 4768 | 300 | 333 | 4435 | |
| 29 | 53 | 1.0 | 940 | 940 | 4080 | 5020 | 300 | 300 | 4720 | |
| 29 | 102 | 1.0 | 894 | 894 | 4080 | 4974 | 300 | 300 | 4674 | |
| 29 | 10 | 0.8 | 651 | 815 | 4080 | 4895 | 300 | 375 | 4520 | |
| March 1 | 68 | 0.8 | 449 | 1186 | 4129 | 5315 | 300 | 375 | 4940 | |
| 1 | 193 | 1.0 | 935 | 935 | 4129 | 5064 | 300 | 300 | 4764 | |
| 1 | 170 | 0.8 | 764 | 855 | 4129 | 4984 | 300 | 375 | 3609 | |
| 1 | 50 | 0.6 | 948 | 1580 | 4129 | 5709 | 300 | 500 | 5209 | |
| 1 | 75 | 0.6 | 192 | 320 | 4129 | 4449 | 300 | 500 | 3949 | |
| 2 | 111 | 1.0 | 608 | 608 | 4162 | 4770 | 300 | 300 | 4470 | |
| 2 | 126 | 1.2 | 857 | 714 | 4162 | 4876 | 300 | 250 | 4626 | |
| 2 | 147 | 8.0 | 2195 | 274 | 4162 | 4436 | 2300 | 287 | 4149 | |
| 2 | 69 | 0.6 | 612 | 1020 | 4162 | 5182 | 300 | 500 | 4682 | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | COLUMN NUMBER |
| | FROM CUSTOMERS CARD B | B-11 | B-9 | (4÷3) | A-4 | (5+6) | [illegible] | (8÷3) | (7-9) | FROM |

Fig. 3 Computation Sheet

tion. This constant $K$ is worked out for every job each time a fuel delivery is made. On the Customers' Card, Fig. 2 (one for each installation), is entered the necessary information and calculations to obtain this job constant. Fig. 2 is a continuous period-by-period record of the fuel consumed on this particular job. An explanation of the entries follows.

Column 1: Starting date of period under consideration.

Column 2: Degree-days corresponding to above date (from Fig. 1, col. 4).

Column 3: Completion date of period under consideration.

Column 4: Degree-days corresponding to above date (from Fig. 1, col. 4).

Column 5: Difference between degree-days written in columns 2 and 4. This entry represents the degree-days which have elapsed during the period.

Column 6: Gallons in storage at beginning of period. (A gage-stick reading obtained from drivers' delivery ticket.)

Column 7: Deliveries during period.

Column 8: Total of columns 6 and 7.

Column 9: Gallons in storage at end of period. (A gage-stick reading obtained from drivers' delivery ticket.)

Column 10: Consumption in gallons during the period. (Entry in column 8 less entry in column 9.)

Column 11: Job constant $K$ obtained by dividing gallons consumed (column 10) by elapsed degree-days (column 5). This is in terms of gallons per degree-day.

Column 12: Job constant $K$, which is in terms of gallons per degree-day per unit load. The unit load assumed is 1000 sq. ft. of steam radiation or its equivalent. In the upper right-hand corner of each card is entered the load on the boiler together with this equivalent unit load, designated as $C$. The entry $K'$ is obtained by dividing job constant $K$ by equivalent unit load $C$.

The constant $K'$ is unnecessary as far as fuel deliveries are concerned, but is important as an index of the overall efficiency of the plant and for comparing fuel consumption of plants which vary in size and manner of heat distribution. A study of the constant $K'$ is of interest in evaluating the various types of building construction, insulation, weather strips, etc.

A comparison of the job constant $K$ with preceding ones is an index of the efficiency of this particular installation during the period as compared with previous periods. Normally these job constants will vary only a few per cent from the seasonal constant, and abnormal variations are immediately reported to our service department. In this manner inefficient operation due to burner equipment's getting out of adjustment is subject to correction before it has become serious from a fuel-consumption point of view, and the results of these corrective measures is immediately known in terms of gallons consumed per degree-day. Fig. 2 gives duplicates of two cards picked at random from our files.

The Computation Sheet shown in Fig. 3 is a tabulation of the daily computations. Actual entries are shown with numbers inserted for names and addresses.

Column 1 is date of fuel delivery. This is the same as column 3 in Fig. 2 for the installation in question.

Column 2 is name of installation.

Column 3 is the job constant $K$ and is taken from Fig. 2, column 11.

Column 4 is gallons in storage after delivery has been made. This entry is the same as in column 9 of Fig. 2.

Column 5 is the degree-days in storage, and is the stock of fuel oil on hand expressed in degree-days rather than gallons. The entry is obtained by dividing the gallons in storage (col. 4) by the job constant $K$ (col. 3).

Column 6 is the elapsed degree-days from beginning of season

to date, and is obtained from degree-day log, Fig. 1, column 4.

Column 7 is the sum of the entries in column 5 and column 6, and represents the "empty tank" point in terms of elapsed degree-days (column 4, Fig. 1). In other words, there would be a run-out of oil on the day in which the total elapsed degree-days from October 1 equals the entry in column 7.

Column 10 is this "fill point" in terms of elapsed degree-days from the beginning of the season. It is found by subtracting entry in column 9 from entry in column 7. A 700-gal. delivery could be made then on the day in which the elapsed degree-days from October 1 (Fig. 1, col. 4) equals this entry (col. 10).

It is now known when any tank will be empty and when it may

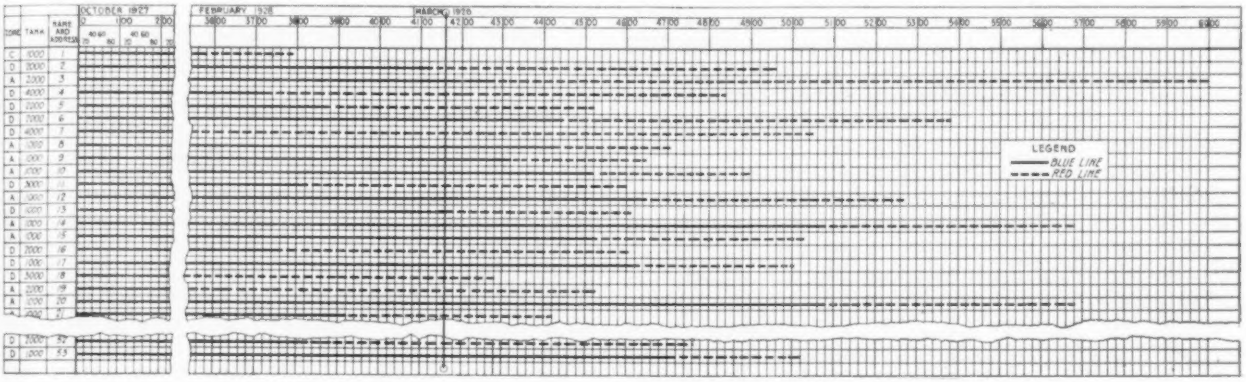


Fig. 4 Wall Chart

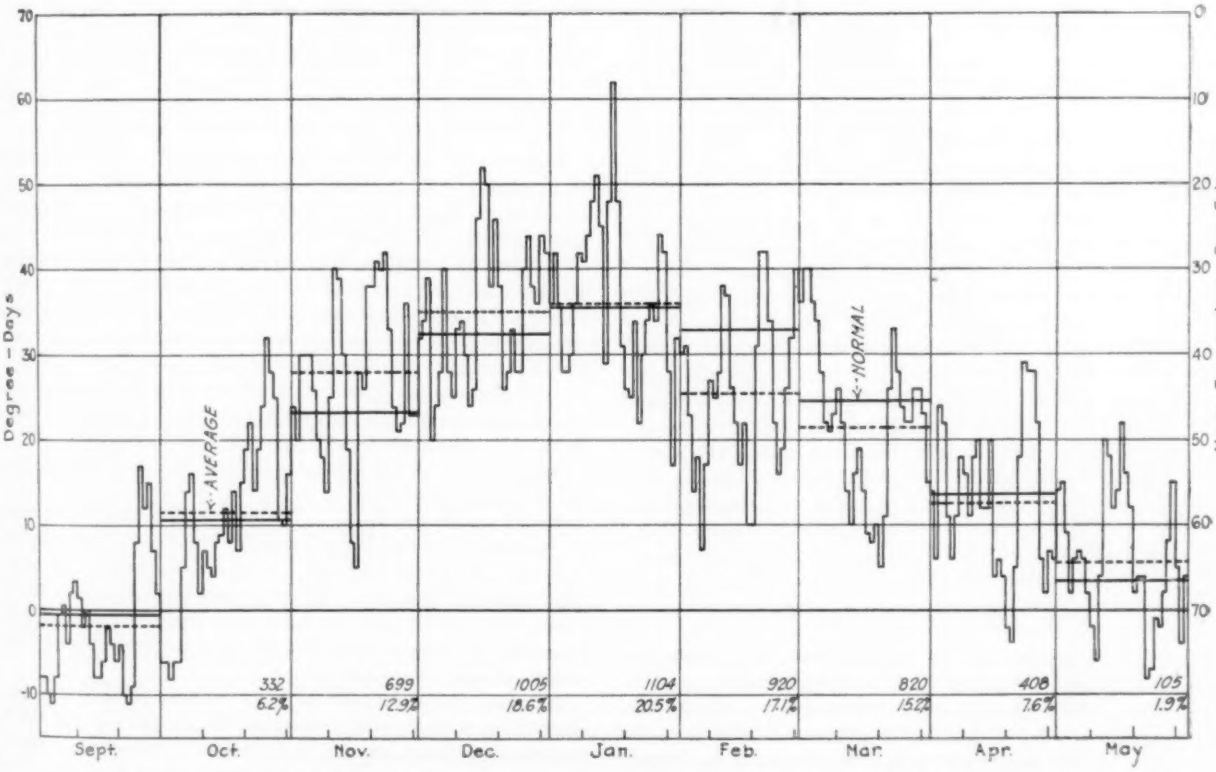


Fig. 5 Chart Showing Relation Between Mean-Temperature Daily Fluctuations and Monthly Averages and Corresponding Degree-Days

Column 8 is the period expressed in gallons which exists between the possible full tank-truck dump point and the empty point. Seven-hundred-gallon deliveries are assumed as standard and the entry in this column, "fill point," is the capacity of customers' tank less 700 gal.

Column 9 is the same period expressed in degree-days and is obtained by dividing gallons in column 8 by the job constant of column 3. It is the degree-day interval which exists between a possible "fill point" and the "empty point."

be filled. The wall chart shown in Fig. 4 is the graphic representation of the fuel-delivery situation. It is posted daily and is the sole source of information for the routing of truck deliveries.

Fig. 4 is ruled vertically and horizontally. The horizontal lines represent installations, and the customer's name and address is inserted alphabetically at each end of the line, together with tankage and delivery zone. The vertical lines are elapsed degree-days from the beginning of the heating season and in the full-size chart are to the scale of 100 degree-days per inch, with the

zero at the left and 6000 degree-days at the right. The average season in our territory contains 5390 degree-days. A vertical guide is moved in a horizontal direction progressively from left to right each day a distance equal to the degree-days corresponding to that day and obtained from column 3 of the degree-day log shown in Fig. 1.

Its position at any day during the heating season coincides exactly with the total elapsed degree-days as entered in column 4, Fig. 1. Its position in Fig. 4 is for March 2 and represents 4162 elapsed degree-days.

The deliveries and tank gagings are posted daily on customers'

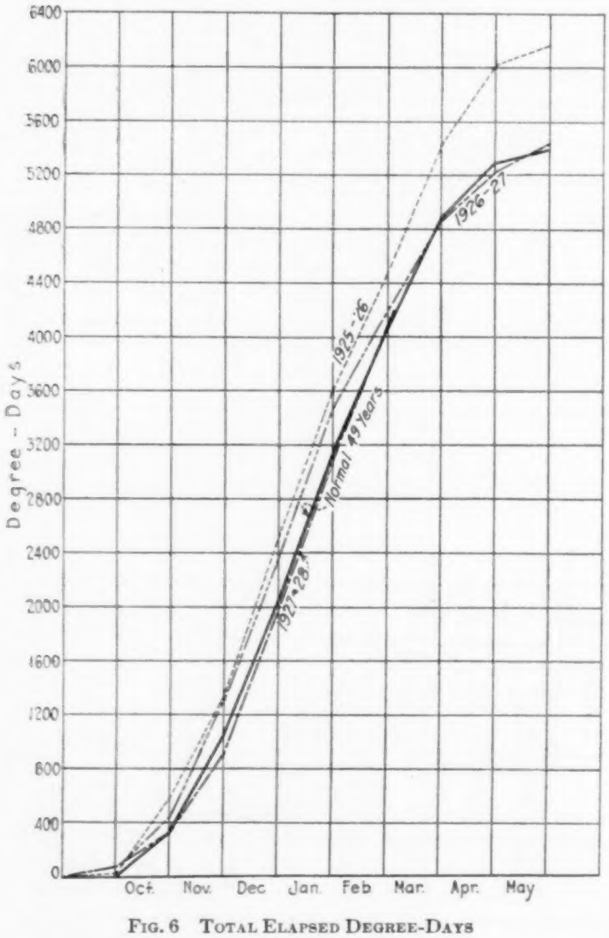


FIG. 6 TOTAL ELAPSED DEGREE-DAYS

cards, Fig. 2, computed on Fig. 3, and the results obtained are marked on the chart Fig. 4 in the following manner:

Centered in the horizontal space corresponding to the installation in question a red-pencil line is projected to the right and terminated at the degree-day point corresponding to "empty tank" conditions, column 7, Fig. 3. A blue-pencil line is drawn in a similar manner terminating at the degree-day point indicated in column 10, Fig. 3, as the "fill point." This blue line covers and obliterates the red line underneath so that the result is a blue line extending to the "fill point" and a red line the remainder of the space to the "empty point." When the traveling guide leaves a blue line and is traversing its extension in red, that particular installation may be supplied with oil in a full tank-truck delivery, and the length of the red line is indicative of the margin which exists between "fill point" and "empty point."

With red and blue lines properly drawn opposite each installation, it is possible to determine by inspection every possible delivery. Knowing the round-trip time for each installation, a schedule is worked out in advance for each tank truck and maximum economy in truck operation is facilitated.

Fig. 5 is a graph showing:

1 Daily fluctuation of mean temperatures and corresponding degree-days for the 1926–27 heating season. (Light full line)
2 Monthly average mean temperatures and corresponding degree-days for the 1926–27 heating season. (Heavy broken line)
3 Monthly average mean temperatures and corresponding degree-days for normal season which is the average of 49 years of weather records. (Heavy full line)

The mean temperature vertical scale is indicated on right margin of the chart, and the degree-day vertical scale on the left.

Time in days and months is plotted horizontally, with the beginning of the heating season at the left.

The total monthly degree-days and its percentage of the total for the season 1926–27 is tabulated in the monthly space under the base line.

Fig. 6 is a graph of total elapsed degree-days.

The time is plotted horizontally.
The total elapsed degree-days from Fig. 1, column 4, are plotted vertically.
The normal (49-year average) season is indicated by a heavy full line.
The seasons of 1925–26 and 1926–27 as well as the 1927–28 season to date are plotted in broken lines.

Posted up to date at frequent intervals, this graph is of value in indicating whether the fuel-delivery demands are running ahead of or lagging behind the normal demand. At just this season of the year (March) the company is making every effort to regulate deliveries so that customers will have a minimum gallonage in storage on June 1 to carry over through the summer season. An empty tank on that date is its goal, but it is not the company's practice to encourage broken tank-truck dumps to attain this end.

Arrangements are made with customers to fill their storage tanks at the company's convenience during the summer months so that the season starts with customers' tankage filled.

Briefly outlined, the following are the various applications of the foregoing information:

*Peak Fuel-Delivery Loads.* The sum of all of the job constants $K$ multiplied by the daily degree-day load gives the daily fuel consumption. Deliveries must of course be geared up to the peak loads of December, January, and February, and the information which is now available simplifies the problem of determining at frequent intervals the relation between total consumption and total deliveries.

Knowing the summation of job constants $K$ on installations already in service, and estimating the summation for the installations sold but not yet in operation, the total gallonage for the season can be predicted very closely, and from Fig. 5 the distribution of this gallonage by months can be estimated. Tank-truck equipment necessary to handle this business may be arranged for and the necessary advance storage of fuel oil anticipated. In estimating the job constants $K$ for installations not yet in service, the installed radiation, estimated equivalent unit load (Fig. 3), and an assumed $K'$ are used as a basis.

*Bulk-Station Location.* The company has considerable suburban territory which is beyond the limits served by the local gas company. A large percentage of the homes located in this territory may be listed as Class A prospects for domestic oil heating equipment. At the present time there is located in the

area a considerable portion of the company's domestic fuel-oil business, and it so happens that in order to make these deliveries the trucks have to traverse downtown streets subject to serious traffic congestion during business hours.

It is proposed to install bulk storage as nearly as possible to the "center of gallonage" of the area referred to. From this storage delivery trucks of 700 gal. capacity will be operated. (The 700-gal. limitation is due to limit loadings on private drives.) To this storage maximum-capacity tank trucks will be operated during the hours which are free from city-traffic delays. On the company's installation map is located accurately every job. The area in question is outlined and each job constant $K$ inserted in the circle representing its location geographically. The sum of the job constants multiplied by the yearly average degree-days, 5390, is the gallonage to be arranged for. Its fluctuation during the year can be obtained from Fig. 5 and the "center of gallonage" or theoretically perfect location of bulk storage computed as a "moment" problem, the factors involved being $K$ (gallons per degree-day) and distance (in miles). The estimated amount of future business must of course be taken into consideration in this survey.

*House Heating and Domestic Water Heating.* In installations beyond the gas-service areas, the company automatically heats the domestic water as well as the residence, and generally with the same oil-burner equipment. This domestic water-heating load is fairly constant and does not fluctuate materially with the outside temperature. The job constant $K$ then must be separated into two parts, one, a domestic-hot-water factor, which is constant, and the other, a heating factor, which fluctuates with the outside mean temperature. The former is determined during the summertime when there is no heating load and is in terms of gallons per day. This quantity multiplied by the days in the period in question gives a quantity which must be subtracted from the gallons consumed, column 10, Fig. 2. The job constant $K$ then found by dividing the entry in column 10 by the entry in column 5 is for the heating load only. In other words, it is possible at all times to make a separation in the fuel consumed with an accuracy within the limits of the company's requirements.

*Sales.* The whole scheme of operation is capitalized in sales work in the following manner:

1 The prospect is offered an opportunity to purchase automatic heat and not just an oil burner.
2 There is an undivided responsibility resulting from a single organization's installing the equipment, servicing it, and supplying the fuel which it is found meets with favor in the mind of the prospect.
3 The prospect is well protected from the hazard of purchasing what might later on become "orphan" equipment.
4 The service organization is financed through the saving effected in direct fuel-oil sales effort. In other words, the service department must be operated for what it would cost to sell the fuel oil by means of salesmen and advertising. In self-protection it is necessary to keep this service cost as low as possible, and in so doing the customer is certain to receive a quality installation as to both material and workmanship. For the same reason it is necessary to be very particular as regards the uniformity and specifications of the fuel supplied.

This degree-day method of fuel-consumption analysis has its limitations, and what has been outlined in this paper may be subject to criticism from a purely engineering standpoint; within the limits of the company's requirements, however, it gives entirely satisfactory results and is easily understood by the layman and the operating personnel.

# Discussion

A. B. Morgan.[2] The application of the degree-day method of estimating fuel consumption to fuel-oil deliveries, as covered in the paper, is most interesting, and there is no reason why it should not be most practical. The degree-day is a comparatively new unit which has come into national prominence within the last ten years. It was originally used in connection with the estimating of total fuel consumption, and served as a very reliable basis for comparing similar installations located in different parts of the country. When used in this manner the mean monthly temperatures were usually sufficiently accurate to yield comparable results. The possibilities of the new unit were further developed by P. E. Fansler of the *Heating and Ventilating Magazine*, who originated an "iso-degree-day" chart which was based on daily mean temperatures. This iso-degree-day chart divided the United States into sections, with comparable total degree-days. Another very important development in this line was the survey made by the American Gas Association which resulted in the establishment of a mean outside temperature of 65 deg. as the temperature at which the average person would operate some form of heating device if automatic heat were not provided.

The relation of the amount of fuel, either oil, coal, gas, or electricity, to the number of degree-days has been repeatedly established and checked for domestic installations. It has even been carried to such a point that it is now indicated that the amount of electricity required to run the motor which operates an oil burner is also proportional to the number of degree-days in domestic establishments.

Even after considering the marked expansion in the use of the degree-day during the past ten years, it is apparent that only the surface has been scratched. This method should be given consideration by all who have problems to solve which involve space heating by any known method.

In the oral discussion which followed the reading of the paper, the use of the degree-day in connection with domestic establishments was not questioned to any great extent, as it was practically obvious that once the particular constants had been established the amount of fuel which would be required by any installation would, under ordinary conditions be practically proportional to the number of degree-days. The practice of using the current daily temperature reports will of course give results which are much more accurate than those based on the normal mean monthly temperatures. A further refinement which might be made where the utmost accuracy is desired would be the use of the temperature or temperatures at which the installation is actually maintained instead of an average temperature such as the 65 deg. determined by the A.G.A. However, it was interesting to note how closely the curves of the total number of degree-days followed each other for a normal year and the years 1925–26, 1926–27, and 1927–28 for the city of Louisville. The practice followed by the author's company of checking the constants at each delivery of oil is an extremely good one, inasmuch as it gives a definite indication of the condition of the particular burner.

Theoretically the degree-day method should be applicable to all types of installations. However, in the case of the hotels, office buildings, and apartment houses there are certain features which must be considered in addition to those of the domestic establishments. For example: in a hotel which is heated by steam at a given pressure, there is a certain amount of fuel required to bring the steam up to that pressure and also to supply process steam for hot water, cooking, etc. Whatever fuel is

[2] Assistant Engineer, National Electric Light Association, New York, N. Y.

necessary to take care of the steam required for process work and losses which are due to the maintenance of fire and pressure so that immediate heat may be supplied, should be considered aside from the fuel which is actually used in heating the rooms. It is therefore obvious that a certain amount of fuel will be required before any heat is furnished to the building. In other words, the total amount of fuel is not directly proportional to the number of degree-days. However, the amount of fuel in excess of that required for the various processes and losses would be proportional to the number of degree-days; this would give a curve which would be in the form of $y = a + (f)\,x$ instead of, as in the case of domestic establishments, $y = (f)\,x$, where $y$ = amount of fuel, $x$ = degree-days, $a$ = constant—dependent on losses and processes, and $(f)$ = function—relation of degree-days to fuel used for space heating.

The preceding paragraph was based on theoretical premises, but recent tests which have been made by a company which supplies steam to hotels, apartments, and office buildings has demonstrated that this method checks fully as close as the simple method in the case of domestic establishments. In conclusion, it is clearly evident that the degree-day method of estimating fuel consumption is applicable to practically all types of service with a fair degree of accuracy. The only question is whether or not the desired information would warrant the necessary labor involved in applying this method to the more complex installations.

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# Distillation and Fractionation in the Petroleum Industry

By H. R. Swanson,[1] New York, N. Y.

*In the author's opinion, with the efforts of refinery engineers in the direction of simplification of the distillation operation and equipment, the single-tower unit would seem to be the solution of a previously complex problem. Contingent matters which must be carefully considered are: (1) the selection of a simple, accessible, and practicable heat-recovery system, and (2) the simplest possible sealed piping arrangement.*

Realizing that increasing competition demanded a reduction of manufacturing costs, the refining industry has been one of the outstanding fields of engineering development during the past few years. This development has of course been apparent in every phase of refining, and we now find a rather general application of improved distillation methods, vapor-phase treating, and contact clay treatment of lubricating oils, in addition to remarkable strides in the field of cracking.

Until quite recently only a few tube stills of the old conventional type were in operation as preheaters, and the general refinery distillation was conducted in shell stills with only primitive tower equipment. The condition of this phase of the refining operation can be taken as indicative of the general condition of the industry when competition was not keen and the margin between raw materials and marketable products was relatively large.

In a paper published in the engineering issue of *National Petroleum News*, David E. Day has stated that, to improve profits from its operation, the refinery must either increase its returns as far as products are concerned, or decrease its costs, or both without sacrifice of quality. Further analysis develops the extreme importance of yields in addition to fuel, labor, maintenance, and chemicals for treating distillates.

It is readily apparent that the solution of this problem, as regards the important items determining the cost of refined products, rests upon the distillation operation. Yield, the most important factor, is controlled largely in the primary distillation unit. The use of a minimum of steam and the elimination of rerunning immediately reduce to a minimum both the direct and the auxiliary fuel. The selection of a simple, compact, soundly engineered, and properly constructed unit insures a minimum labor cost and low maintenance. The improved quality of products from the primary distillation unit cannot but decrease the chemicals and treating costs.

The primary distillation unit, which is obviously the most important phase of the refinery operation, is dependent upon the success of three steps: the heat-recovery system, the main heating unit, and the fractionating system. These three sets of equipment are quite inseparable in the study of a distillation unit and will be discussed somewhat individually but primarily as a complete unit from the standpoint of realization of yield, simplicity and practicability of arrangement, fuel efficiency, and investment. Inasmuch as the yield of products is of paramount importance, any arrangement which could be proposed must necessarily satisfy this requirement. It then becomes a problem of selection of the practicable arrangement.

Originally the tube still was considered a desirable adjunct to the usual shell-still battery, but not a necessity or an independent unit. This condition has entirely changed, and as a result the tube still is now generally recognized as the economical heating unit, not only for crude-oil distillation but for any refinery distillation operation. The increased experience gained by the tube-still manufacturer has contributed to the development of the tube still to a point where units of proper design are now operating with low excess air and resultant overall efficiencies approaching boiler practice.

With the application of fractionating equipment to the refining industry, there developed the logical discussion of the advantages and disadvantages of the various types of recognized countercurrent scrubbing devices. This trial period for the various types found application to shell stills particularly, and along with the widespread application of tube stills, the bubble tower has been quite generally accepted as being more economical as a result of the lower fixed charges and operating costs.

## The Bubble Tower

In consideration of the internal construction of a bubble tower, some important points might be mentioned. Many of the general principles of design, such as the influence of tray spacing, vapor velocity, etc., are generally recognized. However, present developments indicate perhaps too much emphasis has been placed upon submergence as governing contact, apparent velocity through the nozzles, or percentage of nozzle area as governing capacity, etc. The major contact between liquid and vapor for latent-heat interchange is unquestionably in the vapor space above the tray. Perhaps ample provision has not been made for the proper utilization of this ideal contact zone. The proper distribution of liquid and vapor and the elimination of entrainment are interdependent and demand careful consideration.

Several types of tray arrangement have been resorted to in an effort to insure distribution and contact. The true bubble-cap tray arrangements, however, resolve themselves into two general types:

1 The long rectangular nozzle with the long rectangular cap
2 The round nozzle with individual round, square, rectangular, hexagonal, or, in some cases, a long rectangular cap covering several nozzles.

The obvious difficulty encountered with the conventional round nozzle and individual bell cap, as usually arranged on the tray, is the short-circuiting of liquid across the tray, since no path of flow is defined. Such short-circuiting of the liquid inevitably results in unbalancing of the vapor flow, the major portion of the vapor going to the side of the tray where the liquid remains quite stagnant. A tray of this construction may be perfectly balanced if tested by air and water when no water or less than the operating liquid load is being delivered to the tray, but absolutely unbalanced with liquid flowing. In an effort to eliminate the possibility of the unbalancing difficulty, the long rectangular construction has been resorted to as shown in Fig. 1. These nozzles, with caps arranged for individual leveling, ex-

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tend the full width of the tray from a distributing weir on one side to a retaining weir on the opposite side. The liquid delivered at one end of the nozzle follows a definite, unobstructed path across the tray. We have obtained the best results in practice with this type of tray construction. This problem of distribution is relatively simple in small towers and accounts for the apparent success of the conventional construction in the past,

FIG. 1 BUBBLE TRAY

but with the present demand for large units, the inherent advantage of the rectangular cap and provision for definite flow will be more pronounced.

The early application of bubble towers to the industry was on batteries of continuous shell stills which called for a relatively simple tower as a part of a complex unit, as viewed from the standpoint of multiplicity of control. The development of continuous tube-still distillation with all its advantages derived from the very short time the oil is under high temperature, in addition to the economies of operation and maintenance, made imperative the development of satisfactory fractionating equipment for large capacities. The natural tendency was in the direction of a step-up type of unit, which included a tube still and tower for each cut desired. Most of the early units were equipped with partial condensers, which only add to the difficulties of operation and control as compared with pumping back condensate. Fortunately the operation was applied to the production of light distillates only, with a fuel-oil residuum for market or for reduction to coke in the case of paraffin crudes to produce lubricating distillates. It is difficult to conceive of a more complicated set-up than would be necessary if the charge were reduced to an 8 to 10 per cent bottom for the production of the heavier distillates in this type of unit. Obviously, such a complex system with its numerous necessary points of control and duplication of equipment was difficult to synchronize, and particularly difficult to design and balance, except for one particular crude oil, without overdesigning every part for the maximum load condition dictated by various charging stocks. This method is also uneconomical because of the successive overvaporization required to effect fractionation. With this type of unit two salient advantages of modern tube-still installation, simplicity and flexibility, were not realized.

### Multiple-Tower Unit

Sometime ago the many advantages of single-flash over successive-flash vaporization were realized, and the trend was immediately in the direction of the single-flash operation. A paper by Leslie and Goode in the April issue of the *Journal of Industrial and Engineering Chemistry* summarizes very clearly the comparative results of a carefully conducted investigation of vaporization, which checks the results obtained in commercial installations during the past three years. Concurrent with existing practice the multiple tower unit, as shown diagrammatically in Fig. 2, without the heat-exchange flash tower, was the immediate result. The principle of partial condensation for the removal of latent heat at several points is illustrated. This method of heat removal might well be replaced by a plan incorporating a single point of latent-heat removal and arrangement for pumping back from the bottom of each tower to the top of the preceding, but has not been resorted to because of the complicated pumping operation. The outstanding disadvantages of the step-up unit, limited flexibility and complexity of control whether the partial condensation or condensate pump back principle was utilized, were inherited by this type of unit. Progressive steps have been made in the direction of combining some of these towers and arranging for side streams. The complete reduction to a low-bottoms product might be conducted in two steps only with a flash tower for each tube still and one side stream from each tower, but here we have a duplication of con-

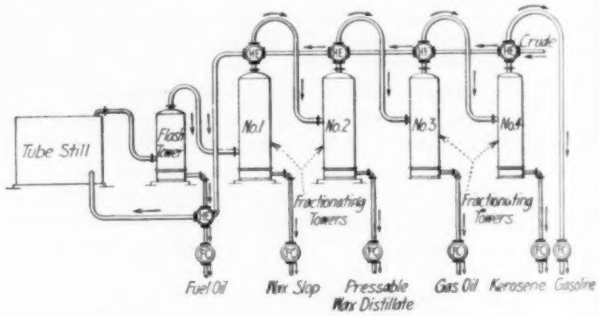


FIG. 2 SINGLE-FLASH MULTIPLE-TOWER UNIT

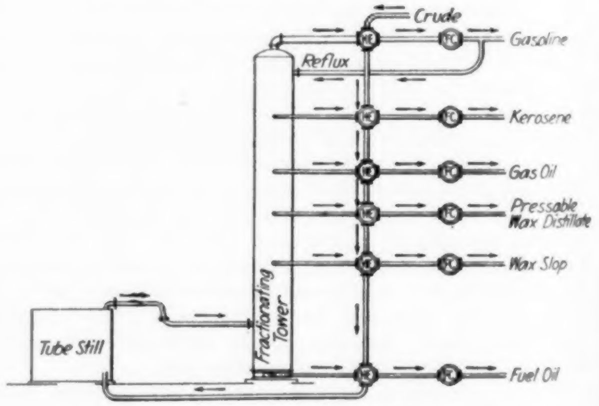


FIG. 3 SINGLE-FLASH SINGLE-TOWER UNIT

trol and lose the inherent advantage of single-flash vaporization in attempting to obtain a minimum of residuum or encounter the necessarily higher temperature for a given type of bottoms cylinder stock.

### The Single-Tower Unit

The next logical step is apparent—the development of a single-tower unit as shown on Fig. 3, which can be considered as derived by placing the series of towers one on top of the other. We can then utilize the condensate pump-back principle for each stream and take advantage of the gravity flow of reflux, eliminating the pumping difficulty except for the pump back to the top tray where the entire reflux liquid is originated. Such a

unit includes only the one source of latent-heat removal, and therefore a single opportunity for a vapor heat exchanger, all other exchanger units being for sensible heat only. The argument commonly voiced against this arrangement is the fact that the main source of heat exchange is at a relatively low heat head, requiring more surface, and because of the low entering vapor temperature the ultimate heat recovery is limited. To meet this argument we might consider the installation of heat exchangers for the condensation of the several streams at points intermediate to the top and bottom, as shown diagrammatically in Fig. 4. When distilling normal Mid-Continent crude oil at a temperature of 800 to 825 deg. fahr. with Navy gasoline from the top of the tower it is possible to recover by the first method about 35 per cent of the heat input of the tube still, and by the second method possibly 45 per cent. The complexity of the second arrangement indicates its impracticability; whereas the first is entirely practicable, simple of control, and flexible. To make the second arrangement capable of handling several crudes with varying yields of the several products would necessitate the overdesign of each intermediate partial condenser to care for the maximum possible cooling requirement, which immediately indicates that the argument of economy of heat-exchange surface is subject to question. Also, it might be noted that of course the whole 10 per cent extra heat recovery would not be realized because of the added stack losses, which would reduce this by about one-half.

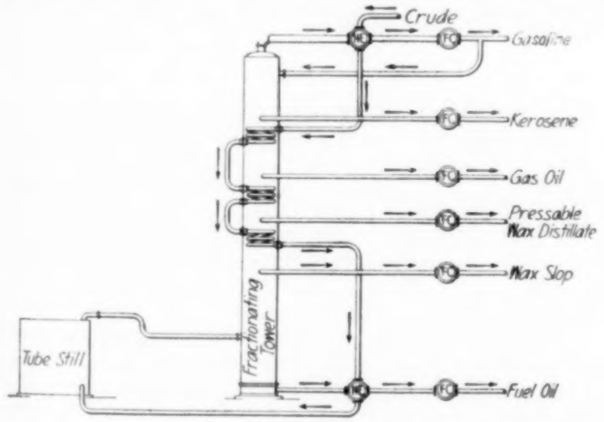


FIG. 4 SINGLE-FLASH SINGLE TOWER WITH INTERMEDIATE PARTIAL CONDENSERS

Obviously, the unit incorporating the single point of latent-heat removal possesses many advantages as compared to others. With a proper type of side-stream control, there remain only two important points of control for the production of any set of products, the tube-still outlet temperature and the top-of-tower vapor temperature. The first is easily controlled by hand regulation of firing with oil, gas, or pulverized fuel, provided the charging rate is maintained reasonably constant. Both are susceptible to the application of standard automatic control equipment.

Inasmuch as the size of the tower is dictated by the top heat load, this type of unit is extremely flexible. The ratio of the various streams may vary widely without affecting the operation or overloading any part of the unit while bringing the unit up to its top heat capacity, which with one set of products or a certain total vaporization may correspond to twice the throughput with another vaporization. It should be noted also that with the single set of heat exchangers, condensers, and coolers for the top vapor stream designed for the lowest anticipated outlet temperature at capacity, the same equipment will be in balance for any higher outlet vapor temperature.

As an example, a unit designed for, and operated with, a throughput of 5000–6000 bbl. of Oklahoma crude with the vaporization of 95 per cent, has also been operated as satisfactorily and efficiently with a throughput of 9000–10,000 bbl. of the same crude with the vaporization of 50–60 per cent. Obviously, the

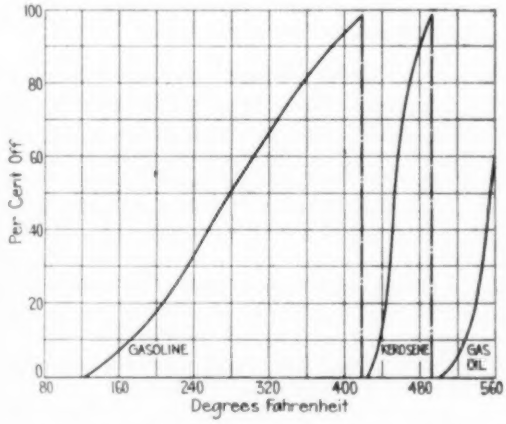


FIG. 5 DISTILLATION CURVES, PENNSYLVANIA CRUDE, LONG-RESIDUUM OPERATION

Charge, 2250 bbl. per day; operating temperature, 525 deg. fahr.; process steam, 12 lb. per bbl. of charge.

Products: Top of tower, gasoline (57.8 A.P.I.); side stream, kerosene (43.9 A.P.I.); side stream, gas oil (39.1 A.P.I.); bottoms, residuum (29.1 A.P.I.).

| | Deg. Fahr. I.B.P. | 50% | E.P. |
|---|---|---|---|
| Gasoline........ | 124 | 276 | 418 |
| Kerosene........ | 424 | 454 | 491 |
| Gas oil.......... | 502 | 555 | ... |

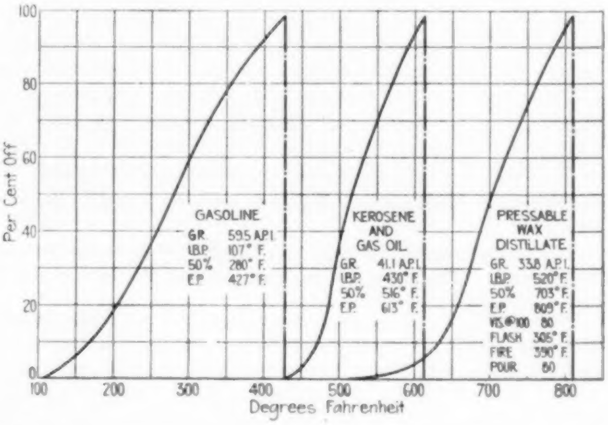


FIG. 6 DISTILLATION CURVES, PENNSYLVANIA CRUDE, CYLINDER-STOCK OPERATION

Charge, 1900 bbl. per day; operating temperature, 725 deg. fahr.; process steam, 15 lb. per bbl. of charge.

Products: Top of tower, gasoline; side stream, kerosene and gas oil; side stream, wax distillate; side stream, slop wax; bottoms, cylinder stock.

| | Sp. Gr., A.P.I. | Viscosity at 100 | Flash, deg. fahr. | Fire, deg. fahr. | Pour |
|---|---|---|---|---|---|
| Slop wax.......... | 29.1 | 235 | 400 | 490 | 90 |
| Cylinder stock..... | 24.5 | 205 | 570 | 660 | 30 |

charge in each case contained the same percentage of gasoline. This variation would not have been possible with a set of multiple towers with partial condensers, such as Fig. 3, with the last tower designed for gasoline from the top since this tower would have been loaded with a throughput of 6000 bbl., even though gasoline only were removed.

Side streams, as commonly removed directly from the tray, possess the characteristic "tail" or small percentage overlap of the next lighter fraction, due among other things to vapor contamination as a result of condensation in the flow line. This can be re-

moved by the introduction of very small amounts of steam into a satisfactory stripping chamber located either inside or just outside the tower, but more satisfactorily and economically within the tower. The same purpose cannot be accomplished as easily or with the same fuel input by a conventional reboiler. Such a stripping arrangement is absolutely essential in producing lubricating distillates to flash specification.

### Typical Distillation Curves

Typical distillation curves of the products from Pennsylvania crude, processed in a single tube still-single tower unit, are shown in Figs. 5 and 6. The unit was originally designed for an operation producing long residuum and Fig. 5 indicates the type of products which were obtained. The two side streams, kerosene and gas oil, were removed from interior stripping chambers and indicate the absence of the "tail" referred to previously, as well as the close boiling range streams possible by close fractionation. Incidentally, the ability to remove a 60–70 deg. boiling-range naphtha with an end point of 430–440 deg. fahr. demonstrated on another unit of this type, proves a decided advantage when a maximum yield of export gasoline is desired.

The same unit is now being operated to produce cylinder stock, and Fig. 6 shows a typical set of distillation curves for the several products. It should be noted that with the limited number of trays in the tower, it has proved advisable to remove the kerosene with the gas oil from the normal kerosene stripping chamber. The pressing stock is being removed directly from a tray, and the wax slop from the normal-gas-oil stripping chamber. Steam is introduced into the bottom of the tower to bring the cylinder stock to flash. No steam was used in either stripping chamber from which the gas oil-kerosene and wax-slop streams were removed. In spite of this, the absence of the "tail" or overlap on the lighter stream will be noted. Unfortunately, no distillation on the slop stream was available. With steam in the stripping chamber, the initial of the gas oil-kerosene stream is normally about twenty degrees above the gasoline end point. The total quantity of steam used in the tower, approximately three-tenths of a pound per gallon of crude or about twelve pounds per barrel, is superheated in a separate convection coil in the tube still.

The production of pressable wax distillate is no longer subject to question. This operation is being successfully carried out on both Pennsylvania and Mid-Continent crudes. The yields straight from the crude, due to absence of cracking, are at least as great as by the old method of operation, including the rerunning. We realize that the pressability is not dictated by gravity or viscosity essentially, or by the so-called "cracking" operation, but by the boiling range. It is obvious that viscosity and gravity could be the same for a long-boiling-range or a short-boiling-range distillate with the same average as cut from the crude, but the one might contain wax which would interfere with the sweating. It becomes of primary importance to take a distillate with the highest possible end point and necessarily of constant specification to insure maximum yield. In operating the single-tower unit, as stated before, two temperatures must be maintained constant to insure the constancy of these streams—the tube-still outlet and the top-tower vapor outlet. With this type of tower unit, as with every other, the specification of any one stream cannot be changed without affecting one or the other, or both, adjacent streams unless an intermediate cut is removed. This fact is not peculiar to this type of unit but this type of unit with the proper tower construction is peculiarly well adapted to the removal of such an intermediate stream with a minimum of difficulty and delay.

As a matter for consideration from the efficiency point of view, the fact that steam is introduced only in the tower and not in the tubes of the tube still, permits the utilization of the exhaust steam from the pumping equipment as a source of supply for the superheater.

### Summary

In summarizing, it might be stated that with the efforts of refinery engineers in the direction of simplification of the distillation operation and equipment, the single-tower unit looms as the solution of a previously complex problem. The contingent problems which must receive careful attention are:

1 The selection of a simple, accessible, practicable heat-recovery system, perhaps at a sacrifice of a few B.t.u., but eliminating the duplication of controls and possible variation of inlet temperature to the tube still.

2 The simplest, but properly sealed, piping arrangement.

Throughout the entire design the engineer must carry foremost in mind a point of paramount importance to the modern refinery, particularly the smaller ones, and that is flexibility.

# The Construction and Protection of Oil and Natural-Gas Pipe Lines

By W. H. T. Thornhill,[1] Tulsa, Okla.

*After calling attention to the magnitude of the underground systems required for the transportation of oil and natural gas, the author considers in detail the methods employed in field construction, dealing successively with surveying the route, purchasing and preparing the right of way, "stringing" the pipe along the route, welding pipe joints, excavating the ditches, lowering of line into the ditch, laying all-coupled lines, etc. He then takes up the subject of river crossings, following which he discusses at length methods of protecting pipe lines from soil corrosion, and the principal requirements which a good protective coating should meet. Such a coating, the author states, provides reasonable insurance against the destruction of large investments in permanent underground pipe lines.*

THE building of oil and natural gas-pipe lines is one of the most interesting and fascinating forms of construction work in existence. Probably this is on account of the constantly shifting nature of the work as it progresses, the fact that speed is always the primary object, and furthermore that it usually involves a more strenuous battle with nature than is customary in other types of construction.

A preliminary map of a projected pipe line is a straight line between two points. Deviations are made with great reluctance and only because of some major topographical condition, such as the elimination of hazardous river or creek crossings, avoidance of cities, towns, or densely populated areas, as well as mountains or canyons, or on account of difficulties of obtaining the necessary right of way. It is surprising how often a completed pipe line is practically a straight line between its terminals.

It is certainly true that the average citizen, when buying a gallon of gasoline or lighting the gas stove, has no knowledge of what has been accomplished in order to make these necessities of modern life so readily available. Most engineers, unless they happen to be in contact with work of this kind, also have very little knowledge of the subject, and therefore it may prove interesting if a brief description of the building of such lines is given.

Oil pipe lines are built to transport oil from producing areas to refineries, ship terminals, or loading racks along railroads. Natural-gas pipe lines of the type under consideration are built from producing areas to large cities to transport the gas for domestic and industrial use as fuel.

Very few persons have any idea of the magnitude of these operations, and a few figures may be of interest.

## Magnitude of Pipe-Line Transportation Systems

There are approximately 90,000 miles of main and gathering oil lines, about 75,000 miles of main natural-gas lines, and 81,000 miles of manufactured-gas lines, the total approximating the railroad mileage of our country. These lines constitute an underground railroad system that is one of the largest and least-known transportation organizations in the world. The various lines are similar to a railroad system in that they comprise trunk lines, gathering or feeder lines, terminals, parallel lines on the same right of way, storage yards, switching systems, stations, dispatchers, and telegraph and telephone lines. Unlike railroads, however, only a single commodity is handled.

Oklahoma and Texas oil is pumped to refining centers either on the Gulf Coast or on the Atlantic Coast, about half-way across the continent. If all the crude oil moved in a year by the various pipe lines were loaded in tank cars, it would require a train 40,000 miles long, or one and two-thirds times the circumference of the earth.

Over $800,000,000 is invested in oil pipe lines alone, without considering the approximately quarter billion of dollars required each year to maintain and extend them.

In projecting the construction of a new oil line such factors are involved as the production in sight, gravity of the crude, length and size of the line necessary, daily production of the well or field to which the line is to be constructed, the probability of the production's being maintained over a long period, the possibility of the producing area's being extended, etc. The factors entering into the construction of a new natural-gas line are also varied, but in general they require a study of the possibility of an adequate gas supply over a long period of years, the feasibility and cost of construction and operation of the pipe line, the necessity of a dependable market diversified in character, the cost of the gas, and other similar items. Furthermore, the cost of the project over the shortest route must be balanced against any possible markets along other longer and more expensive routes.

Fig. 1 Pipe Line Extending Up 45-Deg. Canyon Wall 500 Ft. High

The various elements of the design of the pipe line and its auxiliary features will not be touched upon here, but a description will be given of the methods used in the actual field construction.

## Methods Used in Field Construction

The first necessity, after the preliminary map of the project has been made, is to run a survey in order to determine the best route for the line. Frequently several surveys are made and a final choice of one is determined after a study of the various conditions involved.

Next comes the purchase of the necessary right of way, which

[1] Mid-Continent District Manager for the Wailes, Dove-Hermiston Corp.

Presented at a meeting of the Kansas City Section of the A.S.M.E., May 22, 1928.

often follows closely behind the making of the survey. Pipe-line companies always endeavor to come to a reasonable agreement with land owners, and very seldom exercise their right of condemnation.

The actual construction work is now ready to proceed, and the first or right-of-way gang goes ahead along the course of the proposed pipe line, removing trees, stumps, undergrowth, and grading wherever necessary.

*"Stringing" the Pipe.* Arrangements have previously been made with the pipe companies to ship a certain designated number of carloads of pipe to certain railroad stations most nearly accessible to the proposed pipe line. Distribution of this

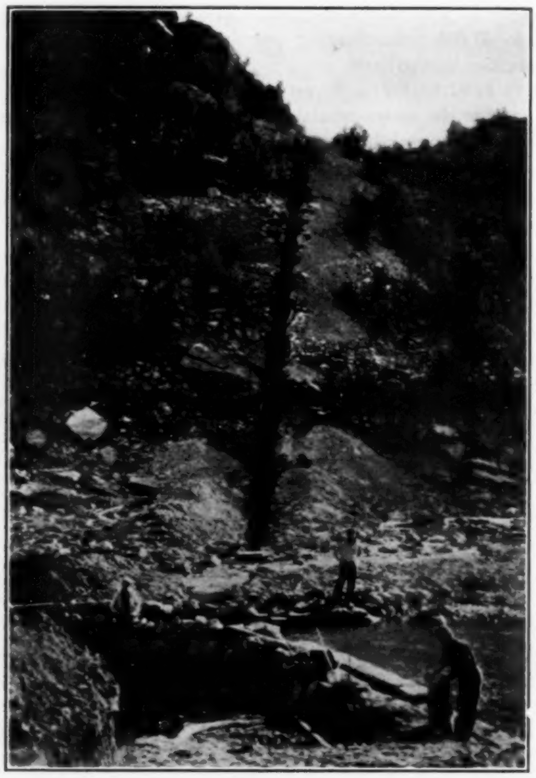

Fig. 2 Pipe-Line Ditch in Solid Rock Across Small Stream and Up Canyon Wall

pipe from these railroad stations is called "stringing." It is necessary that the pipe be handled so that it will not be damaged, and also that it be accurately "strung" along the right of way so that the construction crew will not be obliged to do any extra work in hauling joints forward or backward. Sufficient pipe is stored at each road crossing to span the gap.

"Stringing" pipe is one of the most interesting jobs in pipe-line laying, and usually it is let out to a firm making a specialty of this kind of work. The transporting of the pipe, as well as the other materials required, is a very real problem. Quite frequently the pipe line passes through scarcely populated sections where there are few or no roads, and in many cases roads have to be built.

Wherever possible, motor trucks and trailers are utilized. When these are not practicable, mules and heavy wagons are substituted. Sometimes these cannot get through, as in the case of swamps, and oxen are used. There are cases where pipe and other material have been hauled 80 miles or more over very difficult country.

*Welding Joints in Pipe Lines.* Oil pipe lines have either screwed or welded joints, with a tendency toward all-welded lines today. Most of the main lines are 8 or 10 in. in diameter, with some 12 in. Natural-gas lines are usually coupled or employ a combination of coupling and welding. A few all-welded gas lines have been built. Screw-jointed lines are never used for gas because of the extensive leakage. A welded gas line has been found to have less leakage than one of any other type, but in most instances the engineers fear breaks due to contraction. Main lines for large natural-gas systems usually vary from 16 to 24 in. in outside diameter.

The sequence of the remaining operations varies according to the type of construction. For an all-welded oil line, the next operation is welding. This is done by oxyacetylene flame, although several small lines have been electric-arc welded. An acetylene generator is mounted on a four-wheel truck and moved along the right of way as the welding proceeds. Each generator will supply enough gas for about six welders. Oxygen cylinders are also "strung" along the line.

The usual practice is to have several different gangs of welders for each construction camp, among whom the welding is divided. For instance, one arrangement is to have one gang, known as the "firing line," to weld from 2 to 4 joints. This is followed by a "swing gang" who weld these sections into 400- to 500-ft. lengths. Then follow the "bell hole welders" and bending gang, who tie the whole line into a completely welded unit, make all bends necessary for curves in the line and to follow the grade, and put in railroad, creek, and highway crossings.

Each joint of pipe is cleared out with a swab, in order to be sure there are no obstructions in the completed line, and at night the open end of the completed pipe is closed with a plug in order to prevent animals from entering the line.

*Ditching.* The trench in which the line is to be placed is excavated by means of a ditching machine, of which there are various types. Ditches are dug to a depth that will leave about 16 to 24 in. of soil on top of the pipe. This depth is sufficient to

Fig. 3 Welding of 20-In. Gas Line

keep the pipe line below the usual plowing depth on farms and also below the frost line, so that the temperature changes throughout the year will be very slight. Ditching machines are usually run night and day in order to keep ahead of the construction crews. In case rock is found, the usual practice is to blast it. Occasionally topographical conditions will not permit a ditching machine to operate, in which case hand ditching must be resorted to.

The line is then placed above the ditch on wooden skids, ready for painting and lowering. In some cases where cold paint is used to protect the line against soil corrosion, the application is made before the line is entirely welded together. The best practice, however, is to paint the line after it is over the ditch and just prior to lowering, in order to reduce the possibility of damage

to the paint coating to a minimum. When a skid is encountered the line is temporarily lifted in order to paint the pipe.

*Lowering of Line into Ditch.* This must be carefully done in order not to put any undue strain on the pipe which will cause it to break. The practice is to remove some of the skids, supporting the line in the meantime on a pipe windlass, and then slowly lower this portion into the ditch. By repeating this operation the line is successively lowered in short stretches without damage.

Pipe lines are naturally subject to expansion and contraction underground, due to the temperature changes of the soil in contact with them. Expansion causes no particular trouble, but contraction, on the other hand, will result in breaks. As no expansion joints are used on an all-welded oil line, provision for this contingency is made by lowering the line in the cool, early morning hours, and allowing as much "slack" as the conditions seem to require. Frequently the line is also swung from side to side in the ditch in order to allow it to contract without danger

Fig. 4 Open Ditch 24 In. Wide and 46 In. Deep, With Pipe and Couplings "Strung" Beside It

of breaking. This is an added precaution when a line is laid in flat country.

After the line is lowered, the backfilling gang fill the ditch so it is heaped up with the dirt previously removed by the ditcher. This work is done mechanically in several different ways.

There is now work for the "right-of-way damage man." All during construction, fences have been removed for short sections on farms or gates opened by each gang, in turn, to facilitate the passage of men and equipment. Sometimes these are not closed after a particular gang has passed, allowing stock to escape and damage crops. Ditches at road crossings may not be properly lighted at night, resulting in accidents to persons or livestock. Equipment strays from the right of way occasionally, causing damage to crops. Tile on tiled farms is broken by ditching machines. These are only a few illustrations of occurrences that make life interesting for the damage man. It is surprising, for instance, what an extraordinary value a tree acquires in the eyes of an owner if a few branches are injured during construction work.

*Laying All-Coupled Lines.* An all-coupled or a coupled-and-welded gas line is built with a slightly different sequence of

Fig. 5 Applying Hot Coal-Tar-Pitch Enamel to Oil Line to Protect It Against Soil Corrosion

operations. After the pipe is "strung," the welders come along and usually weld together two or three joints of pipe. If an all-coupled line is being built, this operation is of course not required. Then the ditcher comes along, followed by the painters. Painting is done alongside the ditch. The single or welded joints, as the case may be, are then coupled together over the ditch and made gastight, the couplings and pipe surface immediately adjacent to them are painted, and the line is ready for lowering.

On gas lines of this type, the lowering closely follows the coupling. If long stretches were coupled before lowering, some of the movement of the joints in the couplings, due to lowering, would likely be increased above normal, with the result that the line would pull out of the coupling. If this did not occur, there would certainly be more strain on some couplings than on others, and a leaky joint would result. As each coupling is an expansion joint, no slack is required, but the lowering must be very gradual and very carefully done so that the coupled joints will not be distorted enough to leak when the gas is later turned into the line. Usually on a large-diameter line five or six frames, called "horses," are spaced along the line successively at each joint. Ropes from these "horses" to the pipe support the latter as the skids are removed. These ropes are gradually slacked off their supports to lower the line. The "horses" are continually being moved from the back end of the lowering operation to the front as the lowering progresses. Before lowering, men go along in the ditch to remove any dirt, stones, rocks, etc., that may have fallen into it after the ditcher passed. An all-welded line, such as an oil line closely follows the contour of the country over which it passes, but much more care is required in laying a coupled gas line to secure a more even grade with only gradual and easy changes in the profile.

### River Crossings

River crossings for pipe lines usually present the worst and most difficult construction problems. Special gangs are assigned to this work and are independent of the other construction forces.

River crossings provide the greatest hazard to the continuous operation of the completed line. It is therefore customary practice, especially in the case of gas lines, to install multiple lines. Sometimes as many as six multiple lines are placed across an important river as an insurance of uninterrupted service in case breaks occur in flood times.

Manifolds or headers, with valves, are placed on each side of the river at positions which records indicate will be above the highest water likely to exist during floods. The multiple lines across the stream are then connected to these headers. For some of the shallow sand rivers of the Southwest, these manifolds may be one and one-half miles apart.

It is essential to prevent the river lines from moving after they are laid in position, as otherwise a break will likely occur. The usual practice is to attach a casting weighing from 800 to 1600 lb. and known as a river clamp to the pipe at each welded joint. This strengthens the joint and provides sufficient weight to cause the line to settle to the river bottom and embed itself. Sometimes as an added precautionary measure a collar leak clamp is also placed over the weld and the river clamp placed over it.

Extra heavy pipe is used for these river crossings. Double-length pipe is employed, and all lines, whether gas or oil, are usually welded. River-crossing lines for large-diameter gas pipe are smaller in size than the main line; generally 12-in. is used, but the total capacity of these smaller multiple lines is somewhat in excess of the main line.

If a navigable stream is to be crossed, the Federal Regulations provide that the lines must be buried a certain depth below the river bed. This requires dredging of trenches for the various multiple lines and subsequent backfilling after the line is laid.

For crossing wide navigable rivers, the best practice is to lay the line from a barge. As the barge is pulled by a boat along the course of the pipe line, successive joints are added, river clamps are attached, and the line is painted and then carefully lowered into the river trench. Several sets of lowering pontoons or another barge, following the first one, are used so that the lowering of the line does not put it under too much of a strain. A diver inspects the line after the work is completed to make certain that it has been properly done.

On short navigable rivers, creeks, or sand rivers, the crossing lines are prepared on the shore in as long sections as can be handled and then pulled across into the desired position for each one.

All river-crossing lines are bowed upstream to reduce the possibility of breakage in service. The height of the arc of the bow may be as much as 1000 ft. for a wide river crossing.

In some cases crossings are carried over rivers by special bridges constructed solely for this purpose. This method has seemed necessary in the case of some of the Southwestern sand rivers on account of the shifting nature of their bottoms, quicksands, and similar conditions difficult to combat otherwise.

### Gangs Required and Their Size

In constructing a pipe line, several complete gangs, each with a full set of equipment, are placed in the field at different points in addition to the river-crossing gangs, and the construction work proceeds simultaneously along the different sections. The number of gangs will depend largely on the time available for completing the work, size of line and type of construction, construction difficulties expected, etc. Sometimes six to fifteen or more gangs are in the field at one time, all working on the same project.

The number of men required varies with the conditions. Usually the number of men in each gang for a welded oil line will be from 50 to 100, and for a gas line of large diameter, up to as high as 300.

Because of the shifting nature of the work and the wild country usually encountered, tented camps are utilized and moved frequently. The men are conveyed back and forth to the work each day in trucks. Unless state laws prohibit, work is carried on seven days a week. The camps are carefully supervised to keep them sanitary. An abundance of good food is served, with plenty of variety. This is always an important point as the work uses up a great deal of energy and men quickly become discontented if the living accommodations are poor.

During the construction of the pipe line, pumping or compressor stations, depending on whether the line is intended for oil or gas, are built by a separate organization. An effort is made to have these completed by the time the line is finished so that the entire project can be placed in service immediately. The design, number, and location of these stations are given very careful study so that the most economical operating conditions will be realized. In general, pumping stations are located every 40 miles or more on an oil line, and compressor stations about every 100 miles on a gas line. It is also the usual practice to build a natural-gasoline plant in connection with a gas line.

An oil line pumps from tanks at one station into the tanks at the next one. The movement of the oil is really a succession of individual movements, although all are occurring simultaneously. In effect, therefore, the movement is continuous.

A gas line is different as no holders are used. The pipe line itself acts in the capacity of a holder. The gas never leaves the line, and each compressor station acts as a booster to push it along.

Oil lines operate at pressures around 700 to 900 lb. per sq. in., and gas lines around 300 to 500 lb. per sq. in. The maximum pressure is at the discharge side of the station, and drops off to the minimum at the intake to the next one. It is general practice to use heavier pipe for some distance on the discharge side of a station than is used for the main line. Some oil lines are also constructed of smaller-sized pipe for this part of the line.

### Protection of Lines Against Soil Corrosion

After a line is built the problem which is giving executives of pipe-line companies the most concern is its proper protection against deterioration from soil corrosion. It should be borne in mind that the line is completely buried and out of sight, so that its condition cannot be readily observed. Any structure above ground can be easily watched, and the problem of maintenance against corrosion is a simple one. Usually the failure of a pipe line from corrosion is not known until a break or leak occurs.

C. R. Weidner, chief engineer of the Prairie Pipe Line Company, recently estimated that the loss to the pipe-line owners from soil corrosion amounted to at least $100,000,000 annually. Some engineers believe that this figure is conservative and that the loss is really greater; however, it will convey some idea of the importance of the problem of preventing losses to pipe lines from this cause.

The problem is complicated by the fact that soil corrosion is a most complex natural phenomenon. Instances of differences in rates of corrosion under apparently identical conditions are frequently encountered and baffle any attempt at explanation. It is nothing unusual to discover severe corrosion in a portion of a joint of pipe, while the rest of it, located apparently in the same soil and subjected to the same weather conditions, is still in good condition. Frequently the same thing is true of parallel lines lying within a few feet of one another. In one case a line laid hurriedly with no thought given to any feature of its construction except getting it into service as quickly as possible, was in far better shape after eight years than a parallel one laid with great care four years later. These illustrations could be multiplied many times and are simply mentioned to indicate to some extent the puzzling nature of the problem.

In many cases unprotected underground steel pipe shows no appreciable signs of corrosion for some time, when suddenly a decided increase in the rate of corrosion results in a rapid deterioration. There are cases known where a line was apparently in

good condition four or five years after installation, but three years later was in such bad shape from soil corrosion that replacement was necessary. It is therefore realized that in many cases even a periodical examination of a buried unprotected line is no positive assurance that early failure will not occur.

Of the various methods that have either been proposed or put in practice to combat this condition, the one that seems to be the most practical and is now in the widest use is the application of a protective coating to the outside of the pipe.

There are differences of opinion regarding the various theories of soil corrosion. Every one is agreed, however, that if moisture or other electrolyte can be insulated from the pipe surface, there will be no resulting corrosion. The real corrosive agents are the solutions of the soil surrounding the pipe and not the soil itself. The problem, then, is to provide a satisfactory material which will prevent any of the soil solutions from coming in contact with the steel and continue to prevent it, not only for a short time after the application, but for years to come.

### Requirements of a Good Protective Coating

The main requirements of a good protective coating for permanent installations will now be considered. These requirements are not merely theoretical but are based on a long-time experience with this type of work. They are:

1 It must be waterproof.

2 It must be unaffected by soil acids and alkalis.

3 It must have good adhesion to the pipe surface and maintain its adhesion.

4 It must not disintegrate with age due to internal changes of a chemical nature.

5 It must be incapable of absorption by the soil in contact with it.

6 It must not be affected by underground temperature changes.

7 It must be a dielectric, in order to offer protection against electrolysis.

8 It must be capable of practical application in the field, and at a speed that will not retard the progress of the pipe laying.

9 It must be unaffected by ordinary handling in the field after application and not damaged by lowering into the ditch.

10 It must have a substantial thickness on all surfaces.

11 It must have been in actual use long enough to show actual long-time records of satisfactory performance on steel pipe underground.

12 The cost of using it must be such as to more than justify its use.

The requirement that the protective composition must be waterproof is obvious. Many protective compositions are waterproof when first applied, but subsequently this characteristic is destroyed and the material loses its protective value. A good many bituminous paints contain water, not from design but because no effort has been made to eliminate it. Other materials are manufactured with water acting as a vehicle. It would seem doubtful practice to place a material containing water on a steel pipe line if one of the primary objects in making such an application is to exclude water.

If soil acids and alkalis should have an effect on the coating, or it should lose its adhesion and come off the pipe surface or disintegrate from internal chemical changes, there would naturally be no advantage in using it for protective purposes of a permanent nature. The use of such a coating would be not only of no advantage, but a positive disadvantage, because it would lose its protective value in spots, at which corrosion would be concentrated, and extensive pitting would result. Such a line would probably last longer if no protective coating was used in the first place, because the corrosion would be distributed and not concentrated.

Pipe lines move underground due to temperature changes. Good adhesion of the coating to the steel surface is therefore absolutely essential and must be more than sufficient to meet this condition; otherwise the coating will be torn loose from the pipe, with resulting failure of the pipe from corrosion.

It is also obvious that the coating must not be susceptible to absorption by the soil in contact with it. Some coatings are affected to a considerable extent in this respect by certain types of soil. In general, a soft coating is much more susceptible to this trouble than a hard one.

There is always a variation in ground temperature from winter to summer. This variation naturally depends on the extremes

Fig. 6 Laying 20-In. Gas Line From Pampa, Tex., to Wichita, Kan.

Fig. 7 Laying 22-In. Gas Line From Amarillo, Tex., to Denver, Colo.

of atmospheric temperature as well as on the depth at which the line is buried. In addition the velocity, composition, and temperature of the oil flowing in the pipe line are factors. Accordingly a protective coating must possess a temperature range greater than the underground-temperature variation to be expected in the pipe on which it is to be applied; otherwise the coating will either crack at the low temperature of the variation or become soft enough at the high temperature to sag and flow off the pipe surface. Usually the underground-temperature variation from the low to the high point in the Mid-Continent field is about 40 to 45 deg. fahr. Some protective compositions desirable in other respects have a temperature range of only about 45 deg., but it is possible to obtain a material of a similar base with a temperature range of approximately 80 deg. A desirable factor of safety is provided in choosing the latter composition.

Oil and natural-gas pipe lines are seldom troubled with stray-current electrolysis in view of the fact that they avoid cities and other congested areas. However, for gas or water distributing systems in the cities this is a live problem; consequently it is necessary that a coating be a dielectric to combat this condition satisfactorily.

Invariably in laying a pipe line, speed is the most important consideration. Therefore a satisfactory coating must be capable of application as fast as the other work progresses. Weather or field conditions over which no one has any control enter into the problem of application of any protective composition. This feature will be discussed later.

Pipe-line construction is rather rough work owing to topographical conditions and transportation difficulties, and its shifting location prevents the same carefulness usually exercised in other construction work at a fixed location. The pipe coating after application must therefore be capable of withstanding rough handling without serious injury, otherwise it is hardly practical. In recent years better tools and more careful methods for handling the pipe have been developed, but with the best of care there will likely be some damage to the coating. Therefore it must also be capable of being easily and quickly repaired. The harder coatings without brittleness, but with the best adhesion, fulfil the handling requirements better than the softer ones. Atmospheric temperatures during the time the line lies above the ground must also be taken into consideration. Practically all protective compositions are black, which color has been proved to absorb heat. A coated pipe at an atmospheric temperature of around 100 to 110 deg. will more than likely have a temperature of around 140 or 150 deg. Consequently the coating must not be affected by this temperature to such an extent that it will sag or run off. If this condition should exist, it is common practice to apply a coating of whitewash over the protective composition. If, on the other hand, the work is done in cold weather, the coating must not crack either before or during the time the pipe is lowered into the ditch.

Fig. 8 12-In. River-Crossing Lines Showing River Clamps in Position

A coating may possess all the desirable requirements previously mentioned, but if it cannot be readily applied so that a thickness of at least $^1/_{16}$ in. or more will be obtained, the protection will not be permanent. It is practically an axiom that physical thickness is absolutely essential for permanence. For this reason paints applied cold, which usually have a film thickness of from 0.005 to 0.01 in. per coat, cannot be considered as a permanent protection. Such paints dry by evaporation or oxidation, the result in either case being pinholes and hairline cracks in the film. These openings allow the corrosive agents to reach the metal, with the result that corrosion spreads under the coating and eventually pushes it off. Corrosion is consequently concentrated at these points of weakness and more pitting probably results than if no coating had been applied. Field tests of such materials usually show poor results and indicate their unsuitability for permanent work. If soil conditions are extremely favorable, some measure of protection will be secured from cold applications, but it is being generally recognized that for permanent work underground it will be necessary to adopt some material applied hot.

## Application of Protective Coatings

The hot coatings available are manufactured with either an asphalt or a coal-tar-pitch base. Some of the available coatings require a wrapping of asbestos or wool felt, while others are applied without any wrapping.

In building up a substantial coating it is obvious that a better result will be obtained if a satisfactory thickness is secured from one application of hot material than if several applications alternating with a wrapping are employed. In the first case a thick, homogeneous coating of one material results, and only one application besides the priming coat is required. Wrapped coatings, on the other hand, require from three to five applications in addition to the priming coat, and as a result the possibilities of errors, mistakes, carelessness, etc., in making the application are increased in a corresponding degree. Very careful field work and rigid inspection are necessary to prevent wrinkles, folds, and sags in the coating. Various methods of cutting the wrapping material and applying it have been developed, and it is true that better work is being done now than formerly. However, as it is possible to make a single application of a satisfactory hot coating with a thickness of approximately $^1/_{16}$ in., it is doubtful whether wrapping is necessary to fulfill the requirement of thickness.

It is not practical to wrap the couplings on a gas line, but this drawback has been overcome in some cases by placing a paper or fabric form around the coupling and filling it completely with the protective composition. This method is expensive and not very satisfactory, because leaks are hard to repair.

Wrapped coatings are more expensive than unwrapped ones, especially if more than one ply is used.

There are a great number of different compositions offered today for protective purposes. Experience has indicated, however, that bituminous compounds, which include asphalt and coal-tar materials as a base, are the important ones. Each of these basic materials has its advocates, and therefore a discussion of their advantages and disadvantages may prove of value. The asphalt compounds used in the past for the underground coatings have not given consistent and reliable results. In some cases results seem to be satisfactory, while in others the material seems to have disintegrated and lost its protective value. Sometimes these contradictory results have taken place under conditions that seemed to be identical. Apparently leaching occurred,

leaving a hard, brittle material. This eventually becomes cracked, usually with only fine hairline cracks, but sufficient to allow moisture to reach the pipe. With wrapped coatings the same thing has occurred with the outer coating of asphalt. Moisture then reaches the wrapping, eventually softens it, and causes it to sag away from the bottom of the pipe. This results in a pocket containing water and causes extensive pitting. Hundreds of miles of pipe line coated in this way, which from a superficial examination were considered to be in good condition, were later found to be badly pitted along the bottom of the pipe. A coal-tar-pitch-base compound is being recognized today as a superior material for underground protection against corrosion. It meets all of the requirements mentioned above for the ideal pipe coating, provided the choice of the raw materials entering into its manufacture is based on sufficient experience and knowledge of the physical characteristics of the various pitches and their reaction in combination with the other materials involved in the manufacture of the coating. Most coal-tar pitches, however, have a very narrow plastic temperature range and are unsuitable in many cases for use underground if the variation in ground temperature exceeds the temperature limitations of the material. It is possible, though, to compound a protective composition of an all-coal-tar-pitch base that is not subject to this narrow temperature range, and therefore, in choosing a coating of this type the question needs careful consideration.

It should be borne in mind that there are literally hundreds of coal tars and coal-tar pitches with widely different physical as well as chemical characteristics. Some are absolutely of no value, while others only fulfil some of the requirements of a good coating. The same is true of asphalts. Most of these compositions are simply by-products, and are worthless for the purpose of permanent underground protection. Therefore the fact that a material is designated as having a coal-tar base, with nothing available in the nature of performance records, does not mean anything. An enthusiastic coal-tar advocate will find many good asphalt products far superior to some poor coal-tar compositions, and vice versa.

Many bituminous compositions suffer chemical changes with age, which is one reason why laboratory or accelerated tests are not conclusive. Such tests have a value in that they will eliminate materials of little merit, but there is no test known which will predict the condition of the material in, say, ten or fifteen years. Compositions that pass a test may later prove unsatisfactory on account of subsequent deterioration.

The only satisfactory test is a real service test on a pipe line in the field, preferably in the worst soil conditions. Some companies maintain a "graveyard" for testing. Cinders, salt, sulphur, manure, and similar well-known corrosive agents are mixed with the soil, and then coated pipe is buried in the mixture, which is kept wet. It has been found that the life of coatings in actual service will follow very closely the results predicted by such a test, and consequently it has real merit.

Fortunately, there is a growing tendency on the part of pipe-line men to recognize that a satisfactory job consists of two main factors: proper material for the purpose, and also proper application. Money spent for the best pipe coating in the world might just as well be thrown in the ditch if the application is not carefully and properly made.

The principal requirements in the application of a coating are that the pipe surface must be absolutely clean and dry. All dirt, dust, loose mill scale, rust, grease, oil, or moisture must be removed before any protective composition is applied. This is imperative and applies not only to the main pipe surface but, in the case of a coupled gas line, to all surfaces of the couplings. The best way to clean a pipe line, new or old, is by means of a portable pipe-cleaning machine. It is just as important that the pipe be dry as that it be clean. It is therefore evident that weather and field conditions have considerable bearing on the application. Some officials positively prohibit the application of any protective coating if the pipe is dirty, wet, or frosted, realizing that no coating can be expected to adhere under these conditions.

Field cleaning has been considerably reduced recently and the chances of a more satisfactory pipe coating job secured by specifying that the pipe be given a preliminary coat of the priming solution before shipment from the pipe mills. The extra cost of this preliminary coating is slight and either wholly or to a large extent offset by the reduction of field costs in cleaning. This preliminary field application will not be of much value as a priming coat for the hot material, and should be followed in the field by the customary first coat of priming solution before the hot coating is applied.

The cost of any protective coating must be such that the expected protection or increased life of the pipe will more than justify its use. For permanent lines it is justifiable to spend more money than for temporary ones. Conversely, it is not economic to purchase a high-priced material intended for permanent work if the line is only to be in service for a short time.

In general, costs will be about as follows: For paint applied cold, 1 to 3 per cent of the total cost of the line; for thick unwrapped coatings applied hot, 5 to 9 per cent of the total cost of the line; and for wrapped coatings, 10 to 15 per cent of the total cost of the line. Pumping stations or compressor stations are not included in the total cost of the line. The variation in cost is due principally to dissimilarity in location, topography, field and weather conditions, and also to whether the owner, general contractor, or coating manufacturer makes the application. As a rule it will cost more if the coating manufacturer does the work, for the reason that he supplies a separate organization which necessitates a duplication of trucks, camps, and commissaries. He must also regulate the speed of application to conform with both the laying and ditching. This often necessitates delays or disorganization in his schedule of operations, with a resulting increase in cost. The owner or general contractor can maintain a much better schedule by shifting labor from one operation to another.

When it is realized that the cost of reconditioning a line is usually about three times that of applying a satisfactory protective coating, it seems desirable to adopt the policy of coating all new lines, whether or not the soil conditions are known to be corrosive. Eventually all lines not properly protected may be expected to fail from corrosion and from nothing else. Since there is a lack of complete knowledge regarding the complex problem of soil corrosion, and it is impossible even approximately to predict the life of an unprotected line, a good protective coating provides reasonable insurance against the destruction of large investments in permanent underground pipe lines.

# One Example of Centrifugal Pumps for Petroleum Transportation

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*This paper deals with the problems involved in one specific installation of motor-driven centrifugal pumps for pipe-line work. The author describes conditions prior to the installation, and gives the reasons for the selection of centrifugal pumping units, as well as actual construction and operating costs so far as possible. He also discusses the effect that the experience gained from the installation described may have on the future use of centrifugal pumps in petroleum transportation.*

Recently there has been much agitation as to the relative merits of pumping equipment. A great many comparisons have been made upon purely assumed conditions. It is unfortunate that there are so few actual data available, upon which to base a direct comparison between different classes of equipment, or between different equipments of the same class. The elements entering into pipe-line "cost analysis" are, for the most part, hard to determine; and when once determined, hard to evaluate correctly. Because of this difficulty, some one or more of the component parts are only roughly approximated or else omitted entirely. Every pipe line or station presents its own particular set of problems, and it is wholly unfair to assume that whatever may serve in one case would work equally well in any other. Before a true comparison can be made between any two stations, the whole story should be told, and the existing conditions in each made absolutely plain.

In view of the foregoing statements, this paper will confine itself largely to the problems involved in one specific installation of motor-driven centrifugal pumps for pipe-line work. It has for its purpose, first, the presenting of the conditions prior to the installation; the reasons for the selection of the centrifugal units; and so far as possible, actual construction and operating costs; and second, the effect that the experience gained from this one installation may have upon the future use of centrifugal pumps in petroleum transportation.

The data and information have been furnished through the courtesy of the Oklahoma Pipe Line Company, and the installation referred to is the one known as their Henryetta Station (Fig. 1).

Initially, a 10-in. line had been built between their Cromwell and Council Hill Stations, to provide an outlet for a portion of the oil produced in the Seminole Area. The line was designed to handle 32,000 bbl. of oil per day at 480 lb. pressure. The gravity varied from 35 to 40 deg. A.P.I. and had an average viscosity of about 48 sec. Saybolt Universal at 60 deg. fahr. Some concern was felt as to whether there would ever be sufficient production for the line to operate at its maximum capacity. But, as frequently happens in pipe-line work, the line was hardly completed before it was found necessary to effect an immediate increase in the delivery to Council Hill.

The guide chart shown in Fig. 2 is introduced for the purpose of showing one method that may be employed for the rational selection of pumping equipment but will be discussed only so far as it applies to the equipment selected at Henryetta Station.

Production from a new field is almost invariably well in advance of all storage and pipe-line facilities. Seminole was certainly no exception. As is always the case in caring for a sudden increase in output, the element of time becomes the one item of paramount importance.

To attempt to determine, even approximately, the maximum production of a field, the time required for it to reach a settled figure, or even what this amount would be, is most certainly a hazardous undertaking for any one. However, it was generally believed that the added capacity, so far as this case was concerned, represented a peak load that would only be handled for a maximum of six months. At the end of this time the load would have fallen to the original value of from 30,000 to 32,000 bbl. a day.

It is customary to compare equipment, and in some instances (where ample time will permit) to select it on the basis of the "unit cost per barrel of oil pumped." Even under ordinary conditions "time of operation" is hard to determine. "Time of operation" refers to the length of time the equipment shall operate, and is a very important item in the unit cost figure. Under the stress of "do it now" it seldom, if ever, receives the consideration that it should. It is generally the case that comparative analyses, and more especially where the time for the increase is short, are forced to neglect "fixed charges" and the equipment is selected on the basis of the "time required for delivery." Unit-cost comparisons are investigated at some future date.

There was adequate pump capacity at Cromwell Station for the proposed increase and the problem was to find the quickest way in which the delivery could be made to Council Hill. It was a case of either looping the line or constructing an intermediate booster station. No line pipe was available, and even if there had been, with an adequate amount of time in which to lay it, the expenditure of $528,000 would not have been justified, for the short time it would be used. In order to effect the ultimate increase that has been realized, approximately 37.6 miles of 10-in. pipe, laid from Council Hill and parallel to the old line, would have been required. Computations for a booster station placed it at a point quite close to an existing high line, and electric power could be obtained quickly and easily.

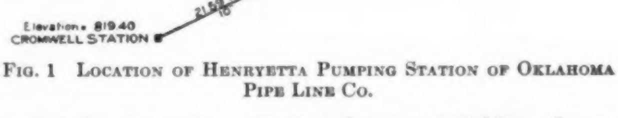


Fig. 1 Location of Henryetta Pumping Station of Oklahoma Pipe Line Co.

Immediate delivery could be made on motor-driven centrifugal units, and as a whole conditions seemed to be ideal for their use. It was realized that the operating cost would be high, but with due consideration for the time saved and the low fixed charges, it was thought that the high rate could be profitably paid for the short time the units would be in service.

Accordingly there were installed two automatic compensator-controlled 300-hp. 440-volt General Electric induction motors, driving two Byron-Jackson 6 × $17^1/_2$ four-stage centrifugal pumps arranged in series and running at a full-load speed of 1750

[1] Oklahoma Pipe Line Company.

Presented at a meeting of the Mid-Continent Section of the A.S.M.E., Tulsa, Okla., December 1, 1927.

r.p.m. Following is a summary of the installed cost of the present completed station. As will be explained later, certain changes were made in the motors. The cost given does not include the expense of making these changes but is given as though the present equipment had been initially installed.

| | |
|---|---|
| 1 Pump-house building and incidental construction, i.e., small storehouse, roads, walks, grading, fencing, etc. . . | $ 3,500 |
| 2 Pumping equipment to include pumps, motors, switchboards, foundations, wire, and miscellaneous. . . . . . . . . | 16,000 |
| 3 Other station equipment, to include 5000-bbl. surge tank, gages, pipe, gates, and miscellaneous fitting and connection work. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | 9,000 |
| Total. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | $28,500 |

and keeping the station in an operating condition. When it was found that the pumps would deliver this quantity of oil, and that the line capacity was adequate, it was thought advisable to correct for the overload on the 600 hp. of motors by installing two of 400 hp. each and operating at 2300 volts.

The increased delivery is explained by the fact that the weather was warm and the oil run fresh from the field at a temperature of 75 deg. fahr. On test the oil showed an average gravity of 38 deg. and a S.U. time of 46 sec. In addition there was actually 155 ft. of fall between Henryetta and Cromwell that was only approximated in the original calculations. In order to protect the motors as much as possible the station was run with a wide-open header gate during the cooler hours of the day, and under

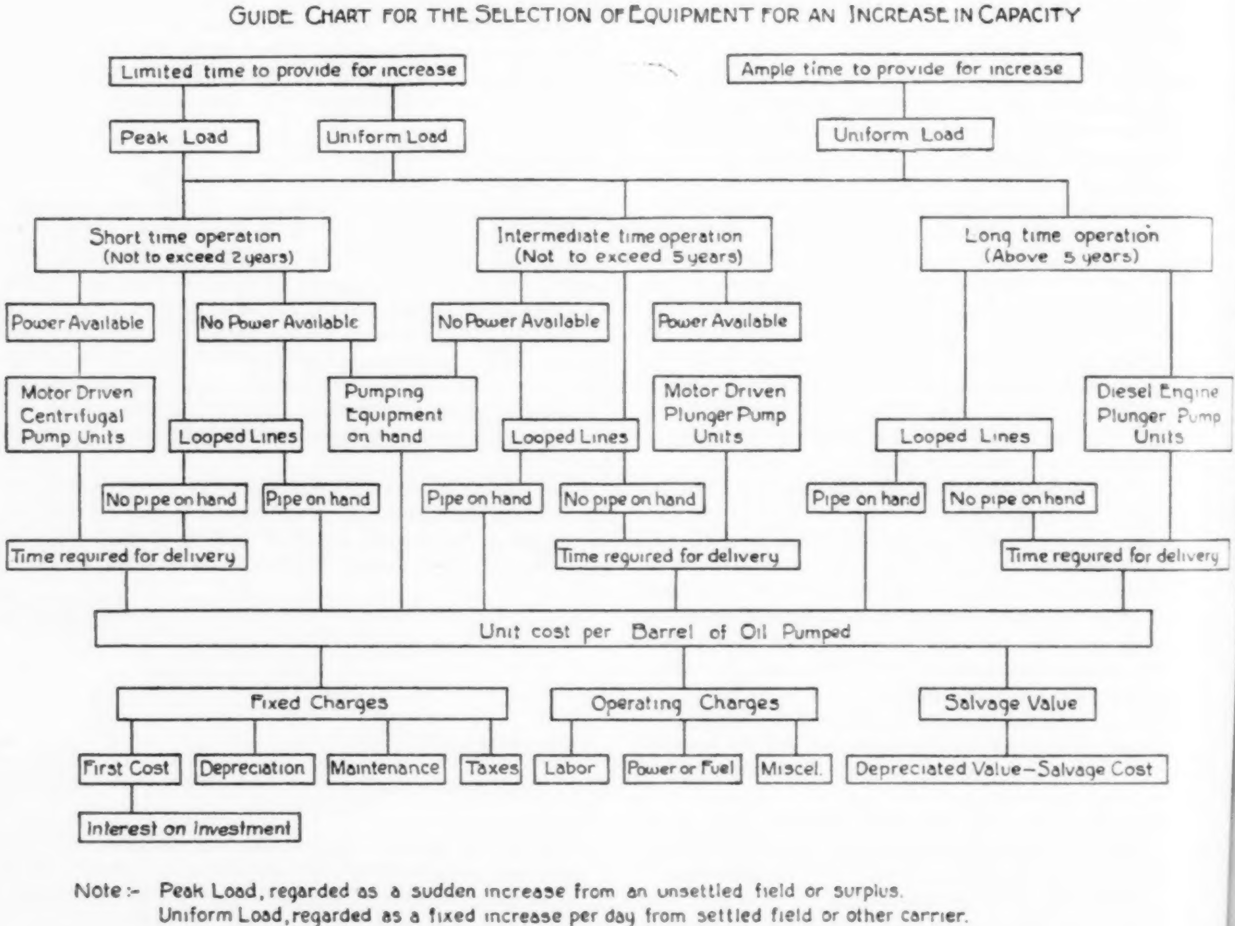


FIG. 2 GUIDE CHART FOR USE IN SELECTION OF PUMPING EQUIPMENT FOR AN INCREASE IN CAPACITY

Local construction conditions for this station were far above the average. If an estimate should be required for a similar installation remotely located and built under adverse conditions a figure of $30,000 would be approximately correct.

The installation was designed for the adverse operation usually experienced in winter pumping and was to deliver 44,000 bbl. of 38-deg. A.P.I., 75 sec. Saybolt Universal oil, at a pressure of 580 lb. Much satisfaction was experienced when the station was started the latter part of April, and it was found that the capacity exceeded that calculated for the assumed conditions. The increased delivery was very much needed, yet it could only be realized at the expense of a very severe overload on the motors. This caused no small amount of trouble in maintaining

this condition delivered around 50,000 bbl. per day at a line pressure of 535 lb. For the remainder of the time the gate was pinched down in order to raise the head and decrease the load on the motors, with a consequent reduction in delivery.

At the present time the oil has a line temperature of about 60 deg. fahr., with a S.U. viscosity of 52 sec. When the header gate is wide open, the delivery is around 51,500 bbl. per day at 580 lb., and no troublesome temperature overloads have developed such as were experienced with the 300-hp. motors.

The following is the result of a brief test made by representatives of the Oklahoma Pipe Line Company and the Oklahoma Gas and Electric Company to determine the approximate mechanical efficiency of the pumps:

TEST OF OKLAHOMA LINE COMPANY'S HENRYETTA STATION, MAY 31, 1927

*Equipment*

Two 300-hp. motors, 1750 r.p.m., 3-phase, 6-cycle, 440-volt
Two 6 × 17½ 4-stage Byron-Jackson pumps arranged in series

*Electrical Data*

SUBSTATION TESTS, 2300-VOLT SIDE OF THREE 2300/440, 200-KVA. TRANSFORMERS

| Kw. | R a/c Kva. | Kva. | Power factor | Transformer losses |
|---|---|---|---|---|
| 592 | 296 | 662 | 89.5 | 22 |

| | Avg. amp. per phase | Avg. volts per phase | Power factor | Kw. input | Hp. input | 92 per cent motor effy., b.hp. |
|---|---|---|---|---|---|---|
| High-duty pump.... | 420 | 448 | 89.5 | 290 | 388 | 357 |
| Low-duty pump.... | 405 | 448 | 89.5 | 280 | 375 | 345 |
| | | | | 570 | 763 | 702 |

*Oil-Pipe-Line Data*

| Line pressure Suction | Discharge | Bbl. per hr. 12 M. to 1 P.M | Viscosity S. U. deg. | Temp. oil, deg. fahr. | Hydraulic hp. |
|---|---|---|---|---|---|
| 12 | 555 | 2057 | 46 | 75 | 466 |

*Efficiency of pump* $\frac{466}{702} \times 100 = 66.2$ per cent

NOTE: A 5000-lb. working tank was installed and the suction pressure of 12 lb. was due to the height of the oil above the level of the pumps at this period. The header gate was pinched down and the pressure given is between the discharge of the high-duty pump and the header gate.

The actual money expended for operation during the months of May, June, July, and August is as follows:

| | | |
|---|---|---|
| 1 Maintenance: | | |
| *a* Material for repairs............ | $ 99.34 | |
| *b* Labor for repairs............... | 613.49 | $ 712.83 |
| 2 Transportation Operation: | | |
| *a* Station, labor, regular.......... | 3,307.42 | |
| *b* Casual labor and misc. (i.e. waste, lamps, brooms, etc.)........... | 470.12 | |
| *c* Lubricating oil................. | 50.53 | |
| *d* Power (1.03 cent per kw-hr.).... | 14,984.44 | 18,812.51 |
| Total........................ | | $19,525.34 |

Total barrels of oil pumped during period.............5,464,002.2
Total energy used, kw-hr...............................1,454,800
Average number of barrels pumped per kilowatt-hour.........3.75
Operation and maintenance cost alone, per bbl., cents.......0.3575

With the foregoing figures as a basis, maintenance is 3.65 per cent of the total transportation cost and is at the rate of 7.8 per cent per year on the present investment of $27,500. This rate of 7.8 per cent is not a true figure; it should be slightly higher due to the fact that the present investment is greater than it was at the time the maintenance figures were taken. It must be remembered that the maintenance cost of $712.83 applies to a time when the station was being placed in operation and that many things were done that would be avoided in the future. Considering the heavy overload that was placed on the motors, it is not unreasonable to assume that the operation was abnormal in every particular. The present 400-hp. motors have not been in operation long enough for a true figure to be determined, but indications are that it will not exceed 3 per cent of the total cost as a yearly maintenance cost.

In order to arrive at an exact cost per barrel of oil pumped it is necessary to take into account the item of fixed charges. For this purpose, the useful life of the station is assumed to be 20 years and the functional depreciation to be taken care of by setting up a 4 per cent sinking fund to provide for replacement. Interest on the total investment is at the rate of 6 per cent, and taxes 3 per cent.

PUMPING COST

(Four months operation)

| | | |
|---|---|---|
| *Fixed Charges* | | |
| Interest on investment.................. | $550.00 | |
| Depreciation............................ | 307.80 | |
| Maintenance............................. | 712.83 | |
| Taxes................................... | 275.00 | |
| | | $ 1,845.63 |
| *Operating Charges* | | |
| Labor, power, and miscellaneous.................. | | $18,812.51 |
| Total.......................................... | | $20,658.14 |
| Unit cost per barrel of oil pumped, cents................. | | 0.3780 |

A comparison between the actual cost at Henryetta and an estimated cost for a motor-driven plunger-pump station of about the same capacity may not be entirely correct, but if all the items are considered some idea of the respective operating costs can be obtained.

50,000-BBL. TWO-UNIT BOOSTER STATION WITH MOTOR-DRIVEN PLUNGER-PUMP UNITS

| | |
|---|---|
| 1 Pump-house building and incidental construction....... | $12,000 |
| 2 Pumping equipment, to include two 300-hp. motors direct connected to two 25,000-bbl. triplex plunger pumps, and miscellaneous........................... | 50,000 |
| 3 Other station equipment, to include working tank and all incidentals........................................ | 13,000 |
| Total.......................................... | $75,000 |

The station is assumed to deliver an average hourly amount of 2085 bbl. of 37-deg. A.P.I., 52 sec. S.U. oil through 25 miles of single 10-in. line at a pressure of 580 lb. Efficiency of the pumps, 85 per cent, and of the motors, 93 per cent. The useful life is assumed to be 20 years, with depreciation taken care of by a 4 per cent sinking fund to provide for replacement; maintenance and taxes taken at 3 per cent and interest on the total investment at 6 per cent. Computations based on 730 hours' operation at a flat rate for power of 1.03 cent per kw-hr.

| | | |
|---|---|---|
| *Fixed Charges* | | |
| Interest on investment.................. | $ 375.00 | |
| Depreciation............................ | 209.87 | |
| Maintenance............................. | 187.50 | |
| Taxes................................... | 187.50 | |
| | | $ 959.87 |
| *Operating Charges* | | |
| Regular station labor.................... | $ 525.00 | |
| Incidental labor, lubricating oil and miscellaneous material for operation....... | 300.00 | |
| Power................................... | 3,500.09 | |
| | | $4,325.09 |
| Total.......................................... | | $5,284.96 |
| Total barrels of oil pumped in 730 hours............... | | $1,522,050 |
| Unit cost per barrel of oil pumped, cents.................. | | 0.3471 |

This would indicate that the plunger-pump station would operate 0.0309 cent, or 8 per cent per barrel cheaper than the centrifugal units. However, for short-time operation, if the centrifugal units could be delivered and installed quicker, this difference can be disregarded.

That a working tank is unnecessary is a point frequently advanced in favor of the centrifugal pump. There are instances wherein this is true, but the unqualified statement will not hold for all cases. For example, the pumps at Cromwell Station were all of the plunger type, and in case of an enforced and unforeseen shutdown at Henryetta, immediate and very destructive

pressures would be built along the line. To safeguard against this emergency, relief valves had to be placed on the discharge lines from the pumps at Cromwell. There is no question that relief valves do afford some measure of protection, but by no means should they be regarded as positive insurance against accident. Further difficulty was experienced at Henryetta due to the low-duty pump pulling a vacuum and hence working at a decided disadvantage. A surge tank was the only logical solution to the troubles, and in addition to providing adequate safety, insured a well-filled pump. Positive local control has everything in its favor, and present experience indicates that a working tank will merit the added expense and should most certainly be installed.

If conditions in the future should be similar to those described for Henryetta Station, there is no doubt that a centrifugal installation would be made. In addition to some of its other advantages, the series arrangement of pumps is very desirable. When their main-line service is terminated they may be used as individual units on local-station work where only a temporary installation is required. Not only are the units compact and comparatively light, and hence can be transported easily, but they require a minimum foundation and housing space and can be installed more quickly than any other unit of even greater capacity.

A serious drawback to the centrifugal pump, and especially with small quantities at high heads, is its low mechanical efficiency. When coupled with an electric motor as a prime mover, the rate that can be paid for power must necessarily be as low as possible. Because of this low efficiency, the power companies should not be expected to compensate for it by furnishing power at a loss. Neither should the power companies penalize the pipe lines because they use the electric motor—in itself a remarkably efficient piece of equipment. It is almost time for the rate makers to adjust their demand and standby charges to fit true conditions. Apparently sufficient consideration has not been given to the fact that pipe-line work is the exact opposite of an industry. The pipe line in general begins with a peak and grades downward; the industry usually starts with a minimum and works toward the peak. It is doubtful if one rate can ever be conceived that can apply equally to both classes of loading. Centrifugal- as well as plunger-pump manufacturers naturally desire the best possible efficiencies for their products, and competition will keep them striving for improvement. Whether they succeed or fail, before the electric motor can retain its rightful place in oil-field work some change must be made in power rates. It is realized that the whole method is relatively new and that present rates may be the nature of an experiment; yet unless there is some revision, power companies are in danger of finding themselves with ample equipment on their hands for service—and no customers.

Pipe lines have been constructed wherein all stations used motor-driven centrifugal pumps entirely, but it is unlikely that this practice will meet with much favor in the Mid-Continent Field when the rates that must be paid for power are seriously considered.

The data that have been presented for this one installation should not be used as a criterion for the acceptance or rejection of the centrifugal unit. Although not entirely defined, the centrifugal pump does have a real place in petroleum transportation, and its use under certain conditions will not only be continued but increased. However, it must be remembered that each installation is to stand on its own feet, and that the selection of any pumping equipment must be made on the basis of existing circumstances.

# Pumping Problems in Paper Mills

## Trash Pump of Recent Design That Does Not Clog When Handling High-Density Paper Stock nor Pull the Water Away From the Pulp

By HELMER N. ANDERSON,[1] ST. PAUL, MINN.

ONE of the most difficult pumping problems in paper mills is that of handling paper stock, particularly where the consistency is 3 per cent or higher. The handling of 5, 6, and $6^1/_2$ per cent paper stock is one that has caused paper-mill engineers considerable concern. For many years vertical triplex single-acting stuff pumps were used, then centrifugal pumps, and finally the non-clogging Wood trash pump came into service.

The vertical triplex stuff pumps are of the outside-packed plunger pattern. The water passages are extremely large and so designed as to give continuous flow. They are usually equipped with large bronze ball valves, which give an easy flow of the paper stock. Triplex stuff pumps have the advantage of being positive-acting machines. The result is that any paper stock that flows into the pump is practically certain of being pumped out. The pump will not clog easily, and being of the positive-displacement type, it will naturally free itself and clear the discharge line in the event that either tends to clog. The efficiency is quite high, resulting in low power consumption.

This type of pump has several disadvantages, however. In the first place, the capacities are low, so that, for example, if a total capacity of 2500 gal. per min. is desired, it would be necessary to install a battery of four or five stuff pumps. This makes the initial investment quite high, and the floor space required is sometimes enormous. In the second place, mechanical difficulties are experienced owing to wearing of gears, replacement of crossheads, pinion-shaft bearings, crankshaft bearings, and crank-pins. In the third place, some difficulty is encountered in pumping the liquid. Occasionally, exceedingly large particles or stringy, fibrous substances accompany the paper stock, and these clog the suction line or the suction-valve passages. Particles which remain on the valve seats are pounded into hard chunks, which results in poor paper. It is thought that the small transparent spots in high-finish papers, known as "shiners," are possibly the results of such masses of pulp.

### Use of Open-Impeller Centrifugal Pumps

Centrifugal pumps with enclosed impellers are used in some paper mills in place of the stuff pumps. The openings are small, with the result that the impellers clog. These pumps are not satisfactory for paper-mill pumping. Centrifugal pumps with open impellers were then designed and furnished for paper-mill work.

The theory of the open-impeller pump (Fig. 1) is that side plates are built into the casing, the pump being furnished with a double suction or single side-suction open impeller, and then any fibrous materials tending to clog would be caught between the impeller and the side plates, thus being cut up into fine enough particles to pass through the pump. The open-impeller centrifugal pump gives fairly good satisfaction, particularly if the percentage of paper stock is 3 per cent or less. This type of pump has the advantage of low initial cost and in addition will handle large capacities with fair efficiency, low power consumption, and a minimum of floor space. Furthermore, the speeds of the pumps adapt themselves for ready direct connection to electric motors.

The disadvantages of this type of pump are that the impeller vanes in the eye of the impeller are sharp, causing paper stock to lodge in the throat. More paper stock will pile up behind this, and finally the pump will become clogged. Any multivane centrifugal pump of the conventional type has a low shut-off head, and therefore the pump will not clear itself once it starts to become clogged. When paper stock is handled heavier than 5 per cent, the water tends to separate from the stock when it is being pumped. Therefore, care must be used to keep the passages straight, uniform, and with the least number of separate channels. The conventional open-impeller pump usually has

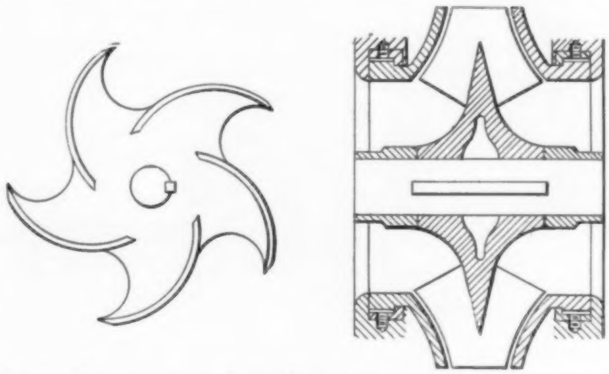

Fig. 1 Conventional Sharp-Blade Open Impeller, Double Suction, With Side Plates

(At the left is shown the side view, and at the right is a sectional view.)

five, six, or seven vanes. This tends to split the fluid into so many separate passages that the water separates from the paper stock, causing the pump to discharge water and some stock, but leaving a portion of the paper stock to pile up in the suction openings.

One of the recent developments in pumps for handling paper stock is the Fairbanks-Morse Wood stock pump. This machine, known as the Wood trash pump, was designed by Mr. A. B. Wood, of the New Orleans Sewerage and Water Board. Mr. Wood has had considerable experience in the very unusual sewage-pumping problems of the City of New Orleans, La. These convinced him that the standard open-impeller centrifugal pump was not satisfactory for the pumping of sewage and other large particles owing to the fact that it clogged continually. Mr. Wood set out to develop a pump that would pass solids practically as large as the discharge and suction openings of the pump and that would handle large solids, twigs, rags, roots, string, and other fibrous material without clogging. He desired a pump with a very steep head-capacity characteristic and with a strong coughing action. This would tend to build up sufficient pressure before the flow would stop so as to clear the discharge line and pump any particles through that might tend to clog. He also desired a unit that would be readily cleanable in the event that extremely large, irregular particles became stuck in the pump and one that would develop a reasonable efficiency over a wide range of capacities.

[1] Manager Pump and Electrical Dept., Fairbanks, Morse & Co.

Contributed by the Printing Industries Division for presentation at the Summer Meeting, St. Paul-Minneapolis, Minn., August 27 to 30, 1928, of The American Society of Mechanical Engineers.

### First Wood Trash Pump

Mr. Wood's first trash pump was a 14-in. unit installed for dredging a sawmill logging pond at Laurel, Mass. This pump gave unusual satisfaction, and the only difficulty encountered

Fig. 2 Wood Pump Impellers

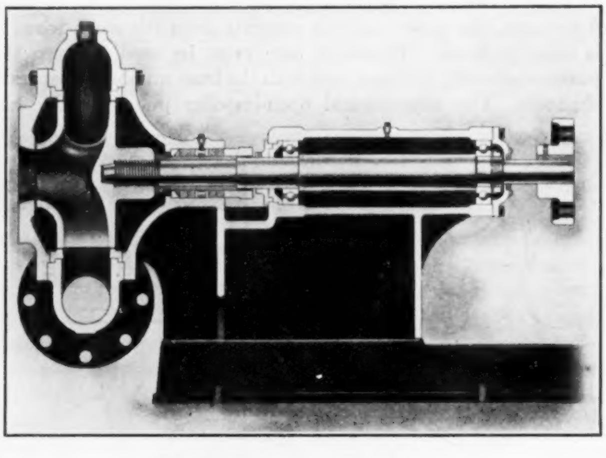

Fig. 3 Section of Wood Pump

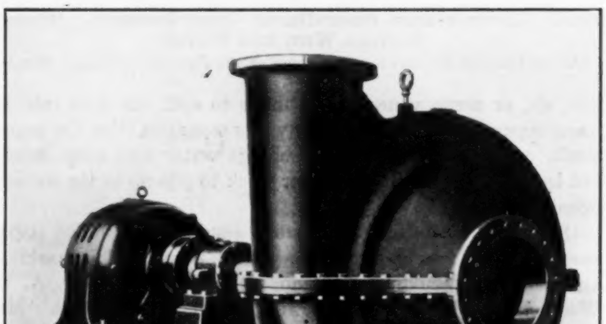

Fig. 4 Horizontal Trash Pump Direct-Connected to Motor

was that the pump endeavored to pick up particles larger than the suction pipe would handle. Such trouble could have been eliminated had a cutter-head or agitator been used to break up the trash. Mr. Wood then designed a 22-in. trash pump and installed it on the dredge *Texas*, the property of the Atlantic, Gulf & Pacific Company, and leased to the Board of Port Commissioners of New Orleans. The pump was driven by a 750-hp. engine, and the complete outfit was placed in operation excavating a canal through a cypress swamp.

Mr. Wood, after these two experimental efforts, then designed and built Wood trash pumps in sizes from 3 in. to 30 in. A large number of these pumps were installed in the City of New Orleans, in the Sanitary District of Chicago, and in other large lift stations and sewage disposal plants throughout the country. However, there is little to indicate that any of these pumps were originally used for handling paper stock.

Fairbanks, Morse & Co., a little over three years ago, secured

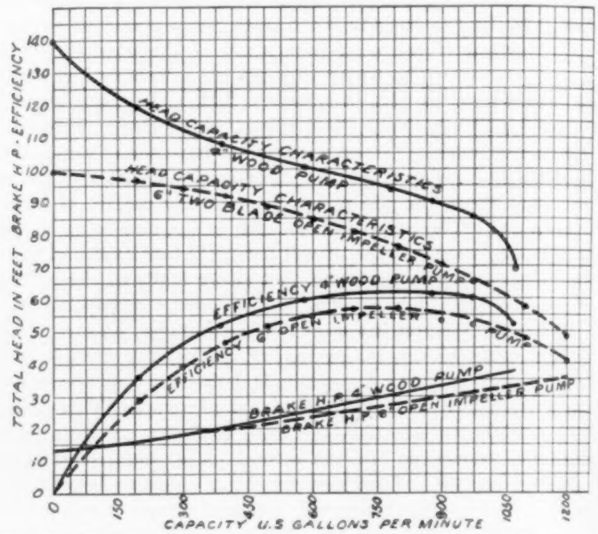


Fig. 5 Comparative Performance of a 4-In. Wood Pump and a 6-In. Pump Having Two-Blade Open Impeller

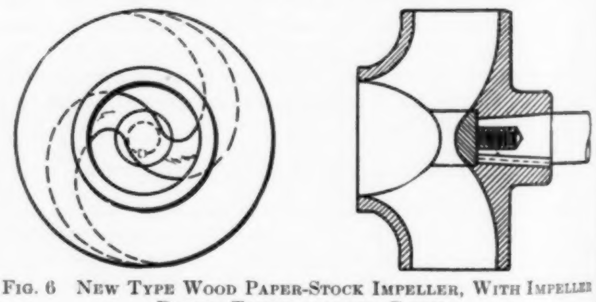

Fig. 6 New Type Wood Paper-Stock Impeller, With Impeller Blades Tapered to the Center

the manufacturing and selling rights under the Wood patents and also obtained the consulting engineering services of Mr. Wood. Thereupon its sales organizations presented many new and interesting industrial problems for the application of Wood pumps, among the most important of which was the pumping of paper stock.

To all outward appearances, the Wood trash pumps resemble the standard side-suction centrifugal pump intended for heavy duty, but the impeller is radically different. It has two vanes so designed as to give absolute mechanical and hydraulic balance. At the entrance, the blades are rounded and the sides or shrouds are filleted, so that throughout the impeller water ways there are no sharp edges, corners, or projections on which materials may catch or clog. The blade gradually tapers to a narrow edge at the outer periphery of the impeller, and the blade and periphery are very smooth (Fig. 2).

The tapering action of the impeller blade, with its low discharge angle, exerts a powerful action on fluids and materials that are being discharged. This crowds out any substance which might tend to clog in the pump; even large solids of irregular shapes are easily expelled. A given particle of material is in contact with the impeller a relatively long period of time. This gives the Wood pump an extremely sharp characteristic curve. The shut-off head is usually double the head at the point of maximum efficiency.

Since the impeller is of the enclosed type, foreign matter does not come in contact with stationary side plates such as are necessary on the older style of open-impeller centrifugal pump. The liquid is promptly discharged through one of the large ports directly into the volute. A saving in power with increased efficiency is thus effected on this type of pump (Figs. 3 and 4). An easy way of visualizing the action of the Wood trash pump is to consider an ordinary pipe tee whirling, drawing the liquid into the center and discharging it from both ends of the tee.

Fig. 5 shows the comparative performance of a 4-in. Wood pump and a 6-in. open-impeller pump of the older design. Both pumps are equipped with impellers 11 in. in diameter and both were tested at a speed of 1750 r.p.m. by the same Sprague dynamometer. The solid lines indicate the characteristic of the 4-in. Wood pump and the broken lines indicate the characteristic of the 6-in. open-impeller pump.

It is interesting to note that the 4-in. Wood pump has a shut-off head of 140 ft. as compared with a 99-ft. shut-off head as made by the open-impeller pump. The wedging action owing to the long tapered vanes of the Wood pumps is the cause of this larger shut-off head. The efficiency of the 4-in. Wood pump is better than that of the 6-in. open-impeller pump, the capacity of the 4-in. pump being practically the same as the 6-in.

### Tendency of Water to Separate

After several Wood pumps had been applied to the pumping of paper stock, it was found this type eliminated many of the difficulties, except that when handling 6 or $6^1/_2$ per cent paper stock the water tended to separate from the stock. When coarse materials such as bagasse are being pumped, this tendency to pull the water away from the stock is very pronounced. This was given serious study by Mr. M. B. MacNeille, manager of the pump division, Fairbanks, Morse & Co., Chicago, and by Mr. Wood, and they came to the conclusion that the heavier stocks, such as high-density kraft, could be handled more effectively if the impeller blades were brought back into the impeller eye and tapered to the center of the hub. The blades could then take hold of this heavy material in the very center of the shaft and immediately begin forcing it outward toward the periphery (Fig. 6). This new type of impeller has been found very effective.

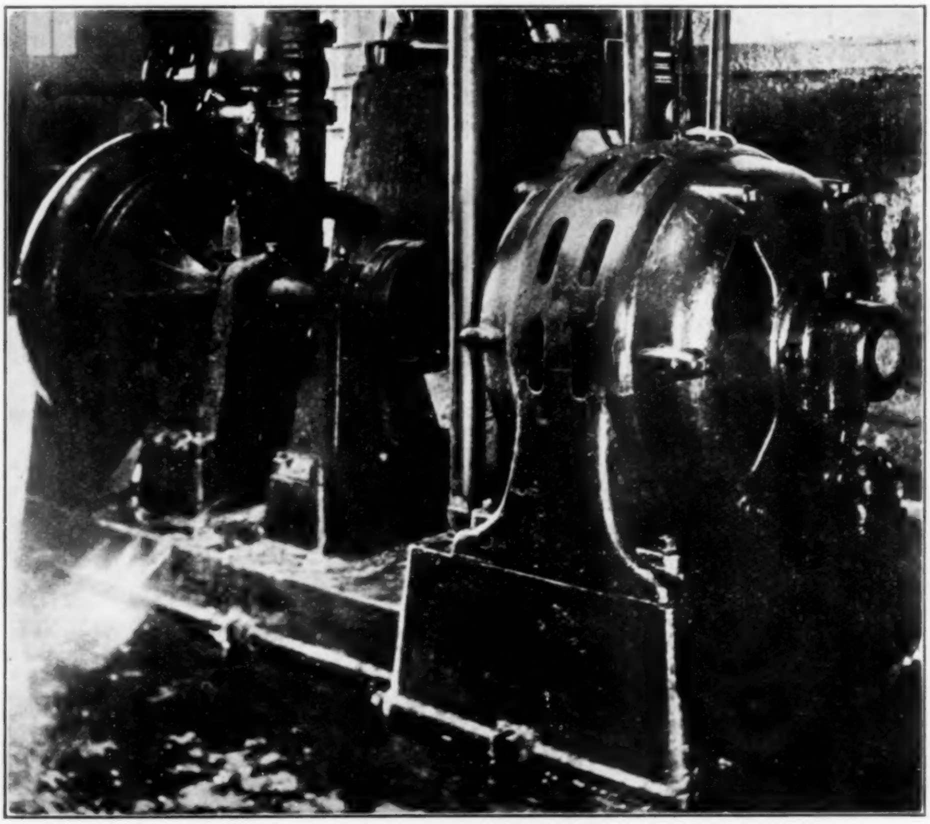

Fig. 7. An 8-In. Wood Pump With 75-Hp. Motor at Eddy Paper Company, Three Rivers, Mich.

A large number of the new Wood pumps with the special stock impeller have been placed in operation. One interesting installation is an 8-in. pump direct-connected to a 75-hp. 720-r.p.m. motor installed in the Eddy Paper Mill at Three Rivers, Mich., for pumping stock from a stock chest to a battery of beaters (Fig. 7). This unit is in daily use and has never had a shutdown caused by clogging, although the stock is not particularly clean. The material handled is of various grades; frequently, the consistency has been over 6 per cent. The total head pumped against, including friction, is 65 ft., and tests have shown discharges considerably in excess of 2500 gal. per min. at this head.

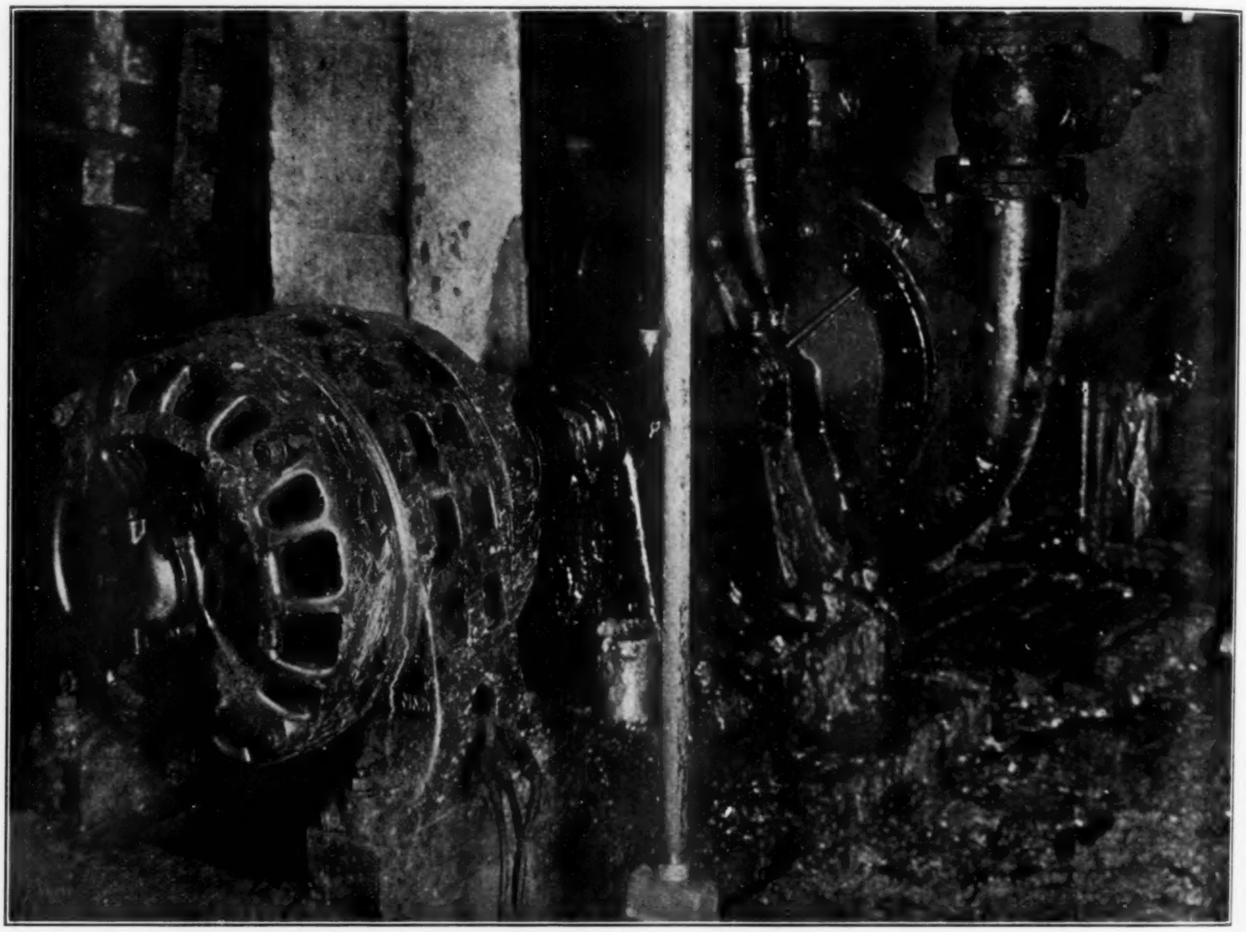

Fig. 9 A 6-In. Wood Pump at Bogalusa Paper Company, Bogalusa, La.

Fig. 10 A 4-In. Wood Stock Pump in Use at Brown Paper Company Plant, Monroe, La.

The Flambeau Paper Company, Park Falls, Wis., has installed a 6-in. horizontal Wood paper-stock pump, direct-connected to a 25-hp. 900-r.p.m. motor. This pump operates against a 70-ft. head and handles 6 per cent stock very satisfactorily. The Waldorf Paper Products Company, St. Paul, Minn., recently installed a 6-in. Wood trash pump arranged for belt drive to a lineshaft. This pump handles 5 per cent paper stock effectively. It delivers 750 gal. per min. against 110-ft. total head which includes pipe friction losses.

Another problem encountered in paper stock pumping is the determination of the correct size of motor required to drive a pump when handling stock of a certain density under a given set of conditions. The power requirements depend upon many factors, some of which are uncertain at present. The capacity desired and static head, or vertical lift, are easy to ascertain. However, the friction losses in the pipe lines are unusually difficult to estimate. Friction tables are available on stocks 4 per cent lighter, but friction losses of heavier stocks must be estimated. For that reason, pumps with steep characteristics will usually prevent the disappointment of obtaining a pump which delivers less capacity than desired. If a pump with a flat characteristic is installed, a few feet more or less may cause the capacity to be seriously reduced, or else to be considerably greater than required.

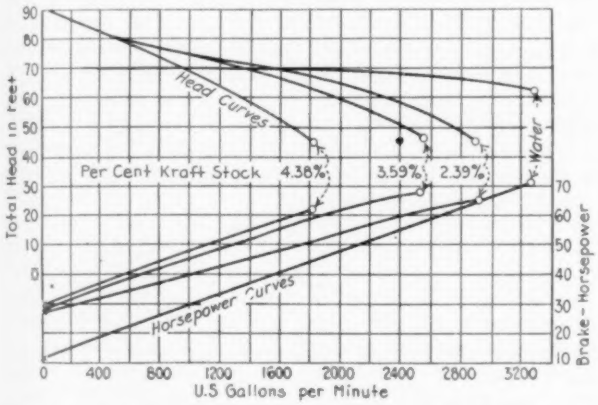


Fig. 8 Comparative Performance of an 8-In. Wood Pump Handling Stock of Various Densities and Handling Water

### Recent Tests Show Horsepower Requirements

Recently a series of tests were run at the Thilmany Pulp & Paper Company at Kaukauna, Wis., on an 8-in. Wood paper-stock pump. A chart has been prepared showing the comparative performance of this pump handling stock of various consistencies as compared with the pumping of water (Fig.8 ). This chart is an interesting study, and undoubtedly the relation will hold more or less for other sizes of pumps. The maximum horsepower required for pumping water exceeds that required for pumping any consistency of paper stock. This may seem unreasonable, but it must be remembered that the capacity of the pump is limited directly in ratio with the heaviness of the stock. The obvious conclusion is that if the size of motor is determined from the maximum horsepower required when pumping water, then no danger from overloads can result, regardless of the consistency of the stock pumped. As more experiments are carried out, more accurate means of determining friction losses and horsepower requirements will result.

The Bogalusa Paper Company, Bogalusa, La., recently installed a 3-in. Wood stock pump direct-connected to an enclosed ventilated motor. This pump delivers 400 gal. per min. of lime-soda solution against a total head of 40 ft. This same company has a 6-in. Wood stock pump direct-connected to a 25-hp. ball-bearing squirrel-cage motor, which handles 300 gal. per min., of 6 per cent sulphite kraft stock against a 72-ft. head (Fig. 9). The Brown Paper Company, Monroe, La., has a 4-in. Wood stock pump working under unusually severe conditions. This pump is direct-connected to a 10-hp. ball-bearing squirrel-cage motor. It handles lime sludge and caustic liquor. Fig. 10 shows the installation of this unit.

The experience encountered in paper stock pumping, together with suggestions and reports given by various paper-mill engineers, have resulted in some additional refinements. The casing on new stock pumps is being split on an angle of 45 degrees so as to facilitate quick inspection. The impeller may be constructed with three vanes where required. Finally, a pulp seal is now being furnished on all wood stock pumps, so as to prevent pulp from working into the stuffing box.

Considerable information on paper-stock pumping is still necessary, particularly knowledge of power requirements. The most economical sizes and kinds of piping, together with friction losses encountered in the pumping of heavy paper stock, have yet to be determined. The most important is the friction of the material itself and it is hoped that additional data and research work will be available in the near future.

### Resume of Advantages

The Wood trash pump has the advantages of the triplex stuff pump in that the efficiencies are good and the power consumption is low. It has eliminated the mechanical troubles such as replacement of gears, valves, pinion-shaft and crankshaft bearings, and plungers, also the difficulties owing to clogging in the passages and to valves pounding portions of the paper stock into lumps.

The Wood trash pump also has the advantages of the centrifugal pump in that the capacities handled are large, the floor space required is small, and the investment is not excessive. The Wood paper-stock pump will not clog when pumping high-density paper stock, string, and other foreign particles such as hats, rags, and sticks, which are encountered in certain classes of paper-stock pumping. With the new type of tapering vanes, no further difficulty owing to the separation of water from the stock is encountered.

## Discussion

M. M. Klosson.[2] This paper was heard with pleasure, first because of the writer's interest in all pumping problems, and second because of his connections with one of the oldest centrifugal-pump manufacturers making extensive investigations of various perplexing pumping problems, one of which has been the pumping of high-density stock. This company manufactures the non-clogging and also the standard open and enclosed impeller, single and double suction, solid and split-shell types of paper-stock pumps, and from experience the writer finds that this paper may give some wrong conceptions of the actual results obtained with different types of paper-stock pumps.

This company manufactures all the various types of pumps, and therefore makes no effort to urge any one particular type, but instead recommends the type of pump best suited for the particular conditions of each installation. Each type of pump has certain advantages which must be considered in order to obtain the most satisfactory and economical pumping unit.

The non-clogging pump, such as the Wood design mentioned by the author, has no special advantages, in a majority of the cases, over a properly designed open- or enclosed-type, single- or double-suction paper-stock pump. The non-clogging type

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of pump, however, is the only type of pump that should be used under conditions of operation where long fiber or rags, string, etc., are to be handled; such, for instance, as are encountered in paper-board mills. There is no advantage in the use of non-clogging pumps in ordinary service where refined or even raw sulphite or paper stock is to be handled. The conventional type of a single- or double-suction pump, properly designed, usually will prove more efficient, equally reliable, and in general more economical.

In order to make this clear the writer made some comparisons of actual tests made by one of the largest paper mills in this

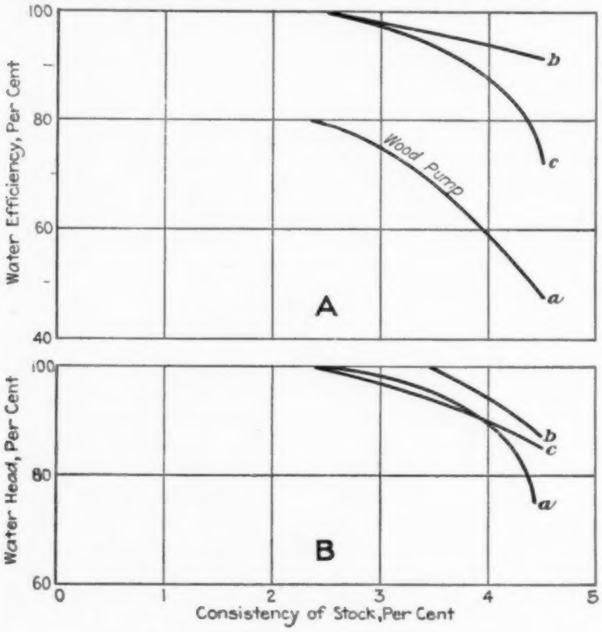


Fig. 11 Curves of Stock Losses

(Curve *a*, 8 in. Wood pump; *b*, 8-in. single-suction Buffalo pump; *c*, 8-in. double-suction Buffalo pump—based on constant capacity and wastehead.)

country. These tests were made on both single- and double-suction, open and enclosed types of impellers. The results are plotted in Fig. 11 against the performance on an 8-in. Wood pump as given by the author.

It will be seen from the curves that the loss of head, in spite of the liberal area claimed for the non-clogging Wood pump, is greater than that for the conventional type of pump. It will also be seen that the loss of efficiency is greater; consequently, less useful work is done for the power consumed than that for either a single- or a double-suction pump, both of which have considerably smaller yet liberal and correct areas.

These curves also indicate that beyond certain liberal water ways there is a disadvantage with a loss of efficiency if the size of water ways is made too large for the given conditions.

The author makes a statement to the effect that the non-clogging pump is better adapted for handling stock of high consistency than is a conventional type of pump. A study of the curves (Fig. 11, *A* and *B*) reveals the fact that the stock losses are greater in a non-clogging pump than they are in a properly designed conventional type of pump.

It will be seen that this particular Wood pump, based on Fig. 8, is capable of delivering 3200 g.p.m. of water against about 64 ft. total head and cannot deliver more than 1200 g.p.m. of 4.38 per cent stock against about the same head. In other words, the pump capacity decreased about 62.5 per cent for 4.38 per cent stock. It is clearly seen that if still higher consistency of stock was to be handled by this pump the capacity would decrease still further. In view of this, it is not clear why the author thinks the Wood pump is better suited for handling stock of higher consistency.

Attention is now called to Fig. 5, showing comparative results of a 4-in. Wood pump and a 6-in. conventional type of pump. The fact that the impellers are of the same diameter and operating at the same speed does not indicate anything nor make a true comparison. In order to make a direct comparison between pumps, it is absolutely necessary to have the shells designed for the same impeller diameter and the discharge volutes in each case perfectly alike. The impeller does not influence the pump efficiency as much as does the casing; consequently, the comparison as shown in Fig. 5 cannot be considered of much significance, and without complete information it may be very misleading. Had there been less variation in the design of the two pumps there would have been less test difference between them, and probably the efficiency would have been higher in the 6-in. pump. High water efficiency does not necessarily mean high stock efficiency, for with proper understanding and selection it is possible to have a pump showing a low water efficiency, but which will, however, have a higher stock efficiency than that of a high water efficiency pump.

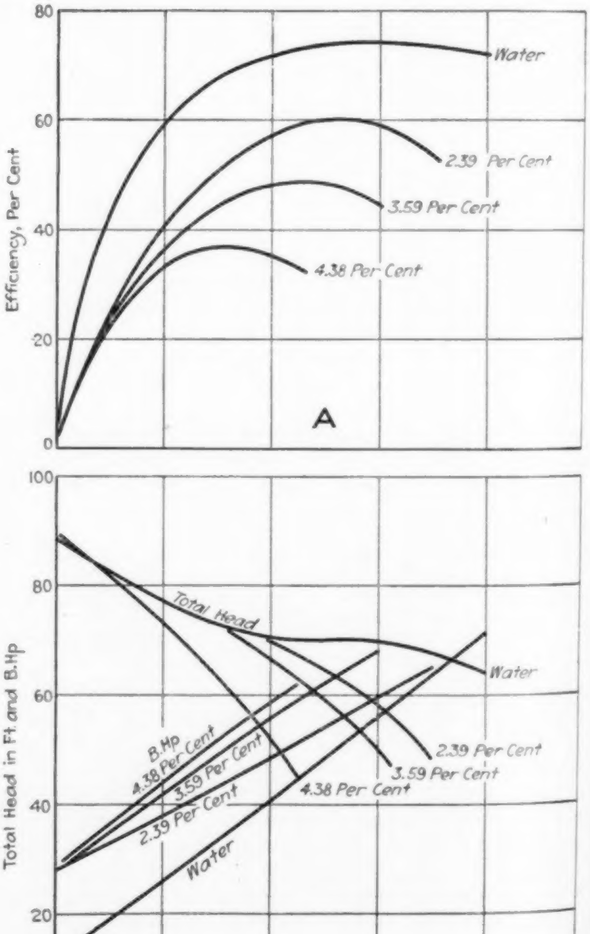


Fig. 12 Comparative Performance of an 8-In. Wood Pump, Based on Fig. 8

It is seen from Fig. 5 that the maximum efficiency corresponds to about 93 ft. head and the shut-off 140 ft., or only about 50 per cent higher, and from Fig. 8 the point of maximum efficiency corresponds to about 70 ft. head and shut-off 90 ft. A statement is made that the shut-off head in the Wood pump is usually double the head at the point of maximum efficiency. The variation between the actual results and the statement requires some explanation.

In reference to the types of head and capacity curves, the writer wishes to add that a steep characteristic curve can be produced with almost any type of pump. In the writer's opinion, pumps with a compromise characteristic—that is, not too steep nor too flat—are best adapted for average operating conditions. A pump with extremely steep characteristic, such as claimed as a standard for a Wood pump, but not shown by the curves, will not usually prevent clogging, as stated by the author. The clogging usually takes place in the direction of flow, and a higher shut-off head, depending on the pipe line, may tend to pack the substance in the pipe and cause a more serious clogging trouble. When the pipe line is clogged on the discharge side of the pump, it is best to clear the pipe by pressure, in the direction opposite to the normal flow.

Another point that must not be overlooked is that a pump with an extremely high shut-off head, with everything else being equal, will consume more power at partial loads than a pump with a flatter characteristic, and consequently with more waste of power.

The description and cut of the special type impeller shown in Fig. 6 and the results obtained with it are all interesting as they confirm the writer's experience of several years ago when a special impeller was designed with the vanes extending into the inlet eye of the runner, and thus the similar troubles were overcome, as has recently been experienced with the original Wood-type impeller.

The writer has made up from Fig. 8 another curve, Fig. 12, which includes efficiencies so that the readers can obtain the necessary information directly. The curves indicate clearly the loss of head and efficiency and the increase of power when pumping paper stock over that required for a corresponding water point. The curve also indicates what the pump user may expect if the pump is selected on the basis of water without considering losses that will take place when pumping stock.

This Fig. 12 clearly indicates that a pump should not be selected on a water but rather on a stock performance, as water performance and especially water efficiency is a very misleading basis; and in proof of this statement it will be noted that the pump delivers 1800 g.p.m. of water against about 70 ft. total head, and when handling 1800 g.p.m. of 4.38 per cent stock it develops only 45 ft. stock head. In other words, there is a 25-ft. loss of head and about 55 per cent loss of water efficiency. Actually the pump efficiency is only about $32^1/_2$ per cent when handling 4.38 per cent stock and about 73 per cent when handling water.

In comparing the results shown in Fig. 5 of a 4-in. Wood pump against a 6-in. open-impeller pump, it will be noted that theauthor credits the higher shut-off head to long tapering vanes of the non-clogging impeller. This statement would lead one to believe that there is a "special new" hydraulic law governing the head developed in a non-clogging Wood pump. This is not the case, however, as the basic laws of hydraulics are the same for all centrifugal pumps, whether of the Wood or other types.

The author says that the maximum horsepower required for pumping water exceeds that required for pumping any consistency of stock; but one must not overlook the fact that such a selection will not meet the conditions of installations, nor will a steep characteristic in such a case prevent disappointment, because a definite capacity corresponds to every pressure developed by a centrifugal pump, as is clearly indicated in Fig. 8. If the stock pump selected on a water basis is to deliver 1800 g.p.m. of stock against a 70-ft. head, it would fail to deliver more than about 1000 g.p.m.

A further study of Fig. 8 will reveal another point that must be charged against the non-clogging Wood pump and especially against the construction. It will be noted that the pump requires 41 b.h.p. to deliver 1600 g.p.m. of water, but the power required is increased to 58 hp., or about 41 per cent, when 1600 g.p.m. of 4.38 per cent stock is delivered against a much lower head. The writer has checked many tests on paper-stock pumps of various types and has never found one that showed such a high increase of power as tests indicate for the Wood pump.

The author says that information regarding pump losses is meager, and this is probably true, but by a consistent study of these problems one is able to separate the various stock losses that take place in a pump and so to solve without much guesswork the problems as they present themselves. The writer trusts that his discussion of the author's paper may be of some value to those interested in the pumping of paper stock and other similar substances.

### Author's Closure

The paper endeavored to point out some of the advantages of the Fairbanks-Morse Wood's patent paper-stock pump when applied to the pumping of high-density paper stock. Mr. Klosson in his discussion mentions that his concern manufactures a non-clogging pump as well as the standard open- and enclosed-impeller pumps. In the first place, to the author's knowledge, the Buffalo non-clogging pump cannot accurately be so named as compared to the Wood pump. Their 6-in. pump has only a 2-in. width of impeller, whereas the same size Wood pump will pass a 5-in. sphere. Furthermore, the Wood pump has the impeller vanes rounded at the entrance so as to prevent clogging of rags, string, and other fibrous material.

Mr. Klosson states that the non-clogging pump is the only type to be used when handling heavy stocks and those containing rags, string, etc. As a matter of fact, the main purpose of the paper was to present the fact that the Wood trash pump would not clog when handling high-density stock nor pull the water away from the stock.

It is true that an open-impeller pump, with close clearances, will sometimes have a greater efficiency when handling light stocks than will the two-vane Wood pump. This is not so true, however, when compared with recent results obtained with the new three-vane Wood pump.

Of far more importance than efficiency are reliability and continuity of operation, low maintenance cost, and prevention of shut-downs. An open-impeller pump, because of the rubbing action of the material between the impeller and side plates, will have greater repairs than will the enclosed-impeller Wood pump with large openings and no close clearances.

The Wood pump is primarily designed for the pumping of fluids containing large amounts of foreign substances. The author made the statement that usually (of course not always) the shut-off head is twice the head at maximum efficiency point. Referring to Fig. 5, we note that the shut-off head is 60 per cent greater, but in Fig. 8 we note that the head at maximum efficiency when handling stock is 45 ft. with a shut-off head of 90 ft., or exactly double.

With the introduction of the three-vane Wood paper-stock pump and with the vanes tapered toward the center of the hub, there is much less drop in capacity and head than in former two-vane units, resulting in considerably greater efficiencies than those shown in Fig. 8.

The author made the statement that pipe-friction losses

(not pump losses) are as yet difficult to determine owing to lack of actual experimental data, to which Mr. Klosson concurs. Considerable study is required with reference to pipe-friction losses when handling 5 or 6 per cent stock. Without this the pump builder is handicapped in ascertaining the correct pumping head. The author therefore repeats that for the present, without accurate knowledge of the total dynamic head, a Wood pump with its steep characteristic curve will often prevent disappointment to paper-mill engineers who desire to move a given amount of heavy stock from one elevation to another.

# Pulp-Grinder Control Reduces Paper Costs

By ADOLPH F. MEYER,[1] MINNEAPOLIS, MINN.

*Large amounts of power are used in grinding wood pulp for use in paper, and unregulated pulp-grinder loads vary greatly and rapidly. This paper describes a governor for controlling waterwheel-driven and motor-driven pulp grinders and points out the economies effected through such regulation. Governors operating on the waterwheel gate are impracticable and undesirable for the purpose of controlling the speed of waterwheels driving pulp grinders. The Meyer governor maintains uniform friction load, and thereby uniform speed, by varying the pressure with which the wood is pushed against the grindstones. As a speed regulator for waterwheel-driven grinders it is actuated by turbine speed. As a load regulator for motor-driven grinders it is actuated by the load on the grinder motors, which it maintains constant. This paper also describes a master regulator by means of which the total kilowatt load on a given system is maintained constant. The master regulator functions through the load regulators on the individual grinder motors. It automatically distributes the increases or decreases in total grinder load necessitated by decreases or increases in load elsewhere in the system, equally or in any other desired proportion, among the several motors by automatically changing the load setting of the individual regulators. The rate of action of the master regulator to correct load changes is proportional to the variation of the total load from normal at the given moment. No electrical contacts or relays are used, yet great sensitiveness is secured.*

WASTE serves no man. In the final analysis, the elimination of waste is the primary source of progress. Instead of attacking the problem of living by means of his hands, as primitive man did, civilized man conserves his limited physical powers and puts his mind at work to coax from old Mother Nature the power genii to do the hard physical work for him. The ways and means of putting these power genii to work efficiently and economically constitute one of the largest fields of man's present activities.

In the production of paper as in all other fields much attention has recently been given to the elimination of waste in all its forms: waste of human life and limb, waste of human effort, and waste of nature's forces and materials. The author will deal primarily with means for reducing paper costs through the conservation and the more economical utilization of nature's forces.

For every ton of newsprint produced about 2400 hp-hr. of power is consumed. Power may be conserved in the production of the groundwood constituting about three-fourths of the newsprint, and the cost of power used in all the pulp and paper mill operations may be reduced by lowering peak demands and filling in the valleys.

## Control of Waterwheel-Driven Grinders

When groundwood is produced with waterwheel-driven grinders, it is essential to maintain the most efficient waterwheel speeds. At first, pressure regulating valves were used. Next, attempts were made to govern by means of centrifugal pumps driven from the turbine shaft. When the speed increased, the pump produced higher pressures, and vice versa. With this type of installation a small measure of control was secured. At least, runaway speeds and the complete stopping of the line were prevented.

Were it not for the fact that the water pressure in the grinder cylinders does not represent the effective pressure of the wood against the grindstone and that the number of pockets in use, the size and character of wood ground, the grindstone surface, and the head and gate opening all vary from time to time, pumps driven from the turbine shaft could have performed a better job of speed control. Today over three-quarters of all the groundwood produced with hand-fed pocket grinders is produced with grinders controlled by Meyer governors. These governors not only force the waterwheels to run at the desired speed, but they permit a degree of control over the quality of the pulp produced that can be secured in no other way.

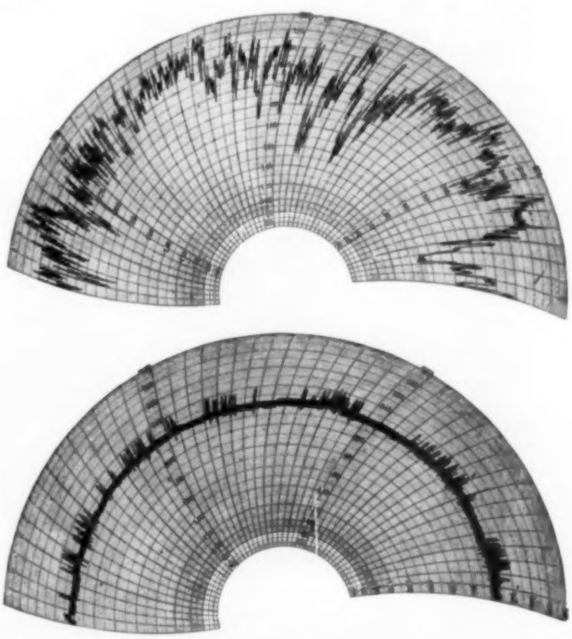

Fig. 1 Typical Tachometer Charts
(Showing speed of waterwheel-driven pulp grinders before and after installation of Meyer governor.)

The final test of whether the groundwood produced is suitable for a given paper is not the blue glass, the freeness tester, the microscope, or the lantern, however useful or necessary these and other pieces of test apparatus may be, but the paper machine; and the final test of the paper made by that machine is the printing press. This, however, does not mean that unfavorable conditions in the printing establishments may not ruin the best paper.

The extent to which Meyer governors have come into use in the mills grinding pulp for news, hanging, catalog, tissue, and book papers in the United States and Canada is in itself proof of the fact that they facilitate the economical production of the desired kind of groundwood.

## Construction of Speed Regulator

The Meyer speed regulator for waterwheel-driven grinders was designed for the severe conditions of the grinder room. Those who are familiar with the slop and the dirt of the average pulp mill realize that it is no engine room or hydro station.

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Contributed by the Printing Industries Division and presented at the Summer Meeting, St. Paul-Minneapolis, Minn., August 27 to 30, 1928, of the American Society of Mechanical Engineers.

This governor is driven by roller chain because in many mills water is continually dripping or even flowing on the drive, making the use of a belt impracticable. Although essentially the governor is extremely simple, yet the details of the design are of the utmost importance since it is a "functional" rather than a "relay" type of machine. An increase in the speed of the waterwheel driving the pulp grinders increases the speed of a rotor producing fluid pressure in a closed chamber, and vice versa. This pressure acting on a large disk and diaphragm produces a force of about 1200 lb., which takes the place of the ordinary hand wheel in adjusting the pressure regulating valve of the governor for a higher or a lower pressure as the speed increases or decreases. By proper attention to details it has been possible to produce large pressure changes with small speed changes without causing hunting.

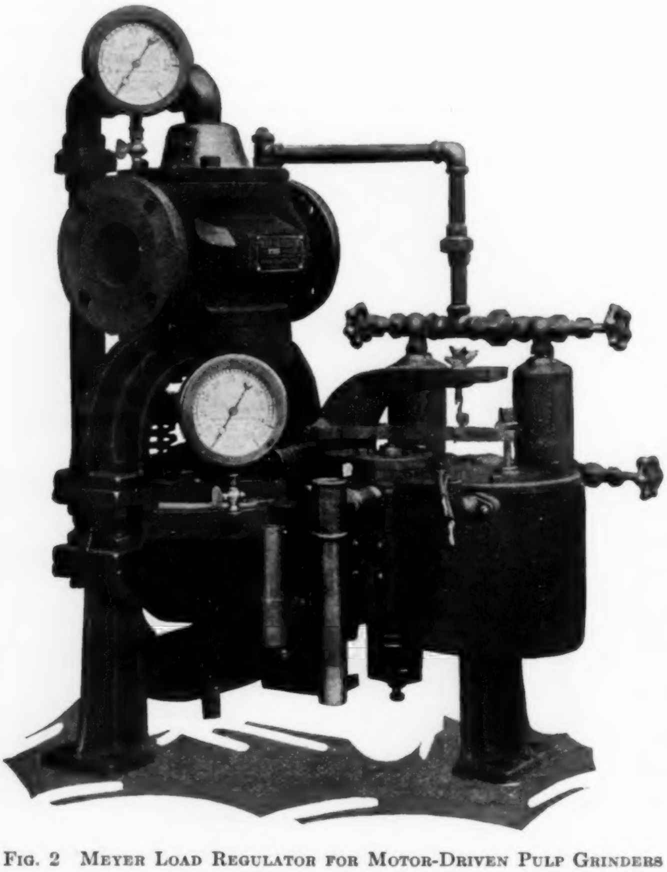

Fig. 2 Meyer Load Regulator for Motor-Driven Pulp Grinders

The valve of this governor is a patented design and is built of Hy-ten-sl bronze. It consists essentially of two sharp-edged, balanced disks closing on flat seats. Dirt will not cause binding. Dynamic effects are practically eliminated. And the valves close remarkably well even after two or three years of wear, when they should have the edges and seats redressed.

Since the governor must operate continuously and since maintenance of small machinery in the grinder room is usually rather lax, ball bearings, gears, and shafts are used that have a rated capacity of about 10 hp., even though the governors require only about half a horsepower to operate them. These parts and their surrounding case, equivalent to the automobile transmission, are designed for an equivalent automobile life of over half a million miles. Each ball bearing is enclosed in a separate casing and supported by a large plain bearing which will come into action if the ball bearing accidentally fails or is not replaced when worn. No gear lubricant can come in contact with the ball bearings. The 600-W used in the gear case is changed after the equivalent of about 25,000 miles of automobile life.

The rotor of the governor produces pressure through centrifugal action, but no space is provided which would permit vortex action as in the centrifugal pump casing. The result is practically instantaneous action without inertia effects. It is sensitive to speed changes occurring several times a second.

Fig. 1 shows typical tachometer charts of the speed of water-wheel-driven pulp grinders before and after the installation of Meyer governors. Besides forcing the waterwheels to run at their most efficient speeds, and thereby increasing the pump output on an average by 10 per cent at no cost but the price of the wood ground, and with consequent reduction in paper cost, these governors also practically eliminate grindstone breakage with the accompanying danger to the men and damage to the grinders.

In most of the pulp mills now being built the grinders are driven by electric motors. Old waterwheel installations cannot economically be electrified except in those mills where the pulp cannot economically be pumped to the paper mill and freight charges are very high. Waterwheels controlled by Meyer governors can deliver to the pulp grinders more power than the same wheels could deliver to electric generators because, by means of this governor, the waterwheel can be run at its most efficient speed for all heads and gate openings, instead of at constant speed at all times. In addition the losses in the generator, motor, and transmission line, and the fixed charges on the additional investment are eliminated. On the other hand, if the pulp cannot be pumped, the cost of lapping, shipping, and beating up again must be charged against the direct-driven installation. Moreover, slush pulp possesses certain advantages.

### Types of Grinders

The ordinary pocket grinder requires 500 to 600 hp. to drive it. Usually one motor drives several grindstones. Most of the old grinders are fed by hand. The large ones, requiring about 1000 hp. each, are fed automatically. Either two pockets fed intermittently by hydraulic cylinders or one large pocket fed continuously by means of chains are used in these grinders. The latest development is the Read grinder, a mammoth machine with chain feed propelled by hydraulic cylinders controlled by a Meyer load regulator. A special chain construction is used on the side of the pockets to eliminate binding, and the direct hydraulic drive for the feed chains insures rapid follow-up capacity in case of slippage or readjustment in the wood.

### Construction of Load Regulator

The Meyer load regulator is designed for use on all types of pocket and hydraulic-feed grinders driven by motors. It maintains uniform motor load by varying the water pressure in the cylinders that force the wood against the grindstones. It is actuated by a large solenoid which exerts a normal pull of 6 to 8 lb. This pull is opposed by a spring by means of which the motor load is set for any desired value. The solenoid and spring oppose each other in pulling on a lever that operates a balanced pilot valve which controls the pressure-regulating valve of the governor and thereby the pressure of the wood against the grindstones. Since this regulator, like the speed regulator previously described, is of the "functional" as opposed to the "relay" type, the proportioning of the parts is of the utmost importance.

By reducing the travel of the plunger of the alternating-cur-

rent solenoid to a few hundredths of an inch, the variation in pull with position of plunger is negatived. The vibration of the plunger keeps the several parts, that have only a few thousandths of an inch travel, from sticking. No contacts are used. The principal advantage of the "functional" as against the "relay" type of regulator is that the former makes a response proportional to the impulse, and action is practically instantaneous. A minor disadvantage is that there must always remain a small residual, uncorrected impulse, which is proportional to the response demanded. Otherwise there would be hunting.

### Load Control Secured

Fig. 2 shows the Meyer load regulator, and Fig. 3 gives typical charts showing how the load curves from the grinder motors were straightened out through regulation. After uniform loads are maintained on the individual grinder motors, the cost of power, and therefore of the paper produced, can be still further reduced by distributing load changes necessitated by other processes in the pulp and paper mill, or variations in miscellaneous light and power or traction loads elsewhere in the system, among the grinder motors so as to keep the total system load constant

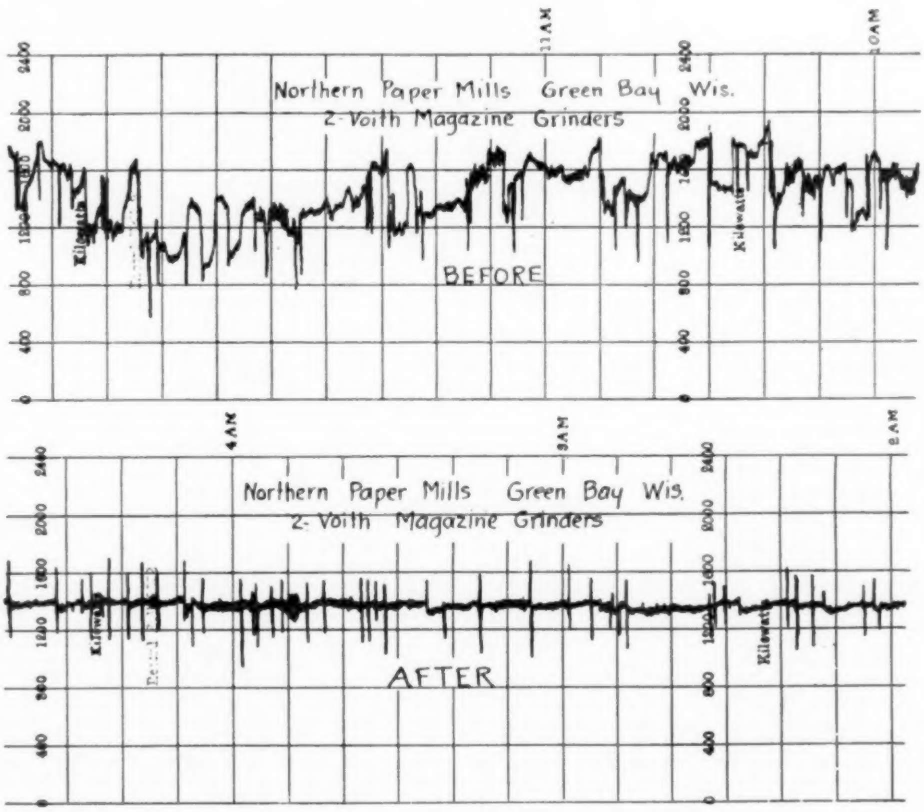


Fig. 3 Typical Wattmeter Charts
(Showing load on grinder motor before and after installation of Meyer load regulator.)

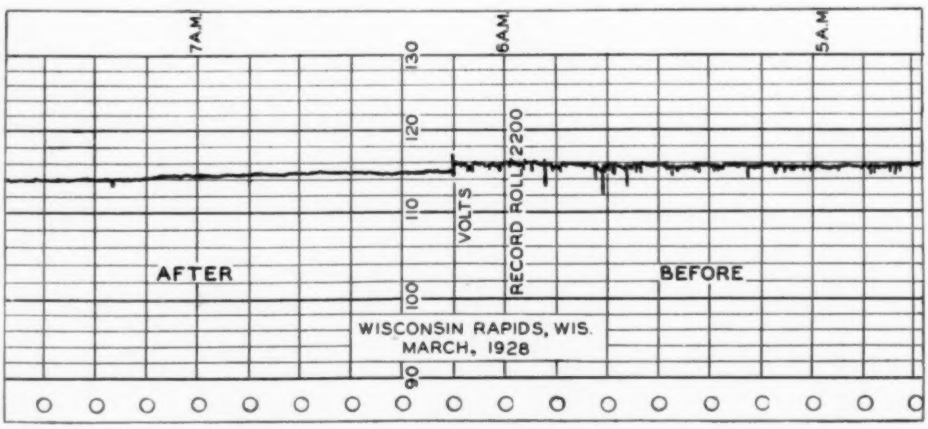


Fig. 4 Illustrating Improvement in Voltage Regulation

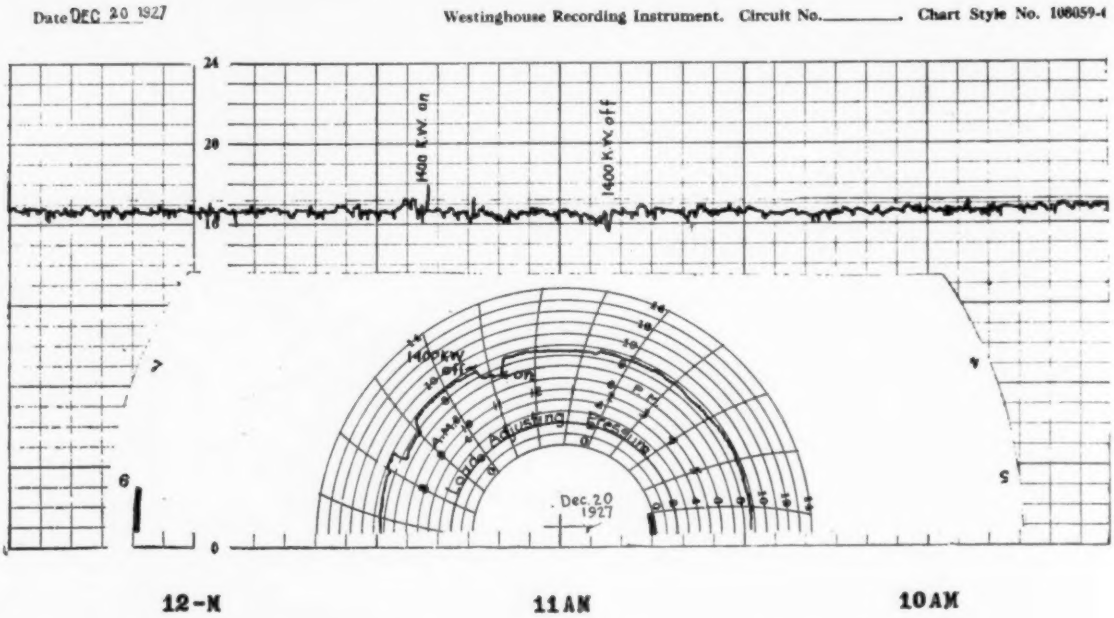


FIG. 5 CHART SHOWING HOW MASTER REGULATOR MAINTAINED CONSTANT TOTAL LOAD
(This was done by changing load-adjusting pressure while 1400-kw. grinder unit was down for temporary repairs.)

from day to day. In one large installation the Meyer system of control increased the daily load factor from below 85 per cent to over 95 per cent. Peak loads were reduced from over 18,000 kw. to about 17,000 kw. Power is purchased on the basis of paying for an entire month at the rate of the highest five-minute demand during that month. The maximum demand is determined from a 4-in.-per-hr. total load chart, and any five-minute period as against successive five-minute periods is used. Such a procedure appears to the author unjustifiable from the viewpoint of any reasonable interpretation of the basic principles underlying peak-load charges. What is the "probability" of random five-minute peaks from a number of plants on one system synchronizing?

Table 1 shows the average load and the five-minute peak load for each working day for a month in the mill referred to. The accuracy of control is attested by the fact that for ten days in succession the peak load was exactly 17,000 kw., as closely as it could be determined from the record made on the large-scale chart.

Fig. 9 shows typical portions of total-load charts from this

TABLE 1 TYPICAL RESULTS SECURED IN CONTROLLING PULP AND PAPER MILL LOAD

| 1927 | Average load, kw. | Peak load, kw. |
|---|---|---|
| Dec. 2 | 16,868 | 17,000 |
| 5 | 16,943 | 17,000 |
| 6 | 16,946 | 17,000 |
| 7 | 16,876 | 17,000 |
| 8 | 16,979 | 17,000 |
| 9 | 16,763 | 17,000 |
| 12 | 16,780 | 17,000 |
| 13 | 16,755 | 17,000 |
| 14 | 16,784 | 17,000 |
| 15 | 16,796 | 17,000 |
| 16 | 16,693 | 17,100 |
| 19 | 16,726 | 17,000 |
| 20 | 16,713 | 17,100 |
| 21 | 16,609 | 17,100 |
| 22 | 16,793 | 17,000 |
| 23 | 16,713 | 17,000 |
| 27 | 16,689 | 17,000 |
| 28 | 16,843 | 16,900 |
| 29 | 16,871 | 16,850 |
| 30 | 16,826 | 17,100 |
| 1928 | | |
| Jan. 3 | 16,868 | 17,000 |

The peak-load readings must be corrected for transformer efficiency by dividing by 0.9825. Missing records indicate holidays or other days on which the mill was shut down wholly or in part.

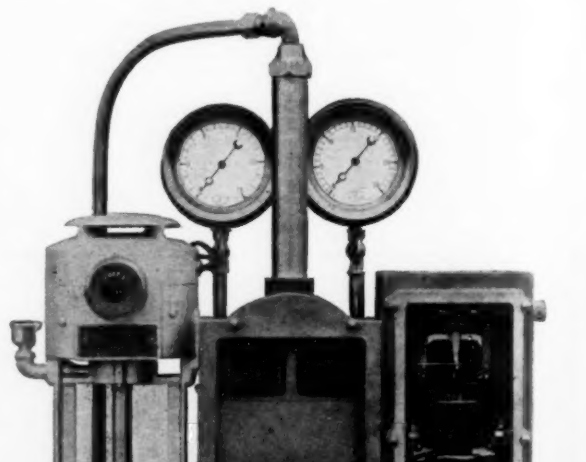

FIG. 6 MEYER MASTER REGULATOR FOR MAINTAINING CONSTANT TOTAL SYSTEM LOAD

mill before and after the installation of the Meyer system of load control, consisting of regulators for the nine grinder motors and a master regulator for the total load.

Fig. 5 shows that the master regulator maintained a uniform total load while a 1400-kw. grinder unit was down for half an hour for repairs. It added one-eighth to the existing load on the other eight motors. The master regulator accomplished this by changing the pressure in the hydraulic load adjusters of the individual load regulators. In this particular instance the load on six banks of transformers, representing different amounts of power, is added up by six similar General Electric Co. watt elements and maintained constant. No electrical contacts or relays are used.

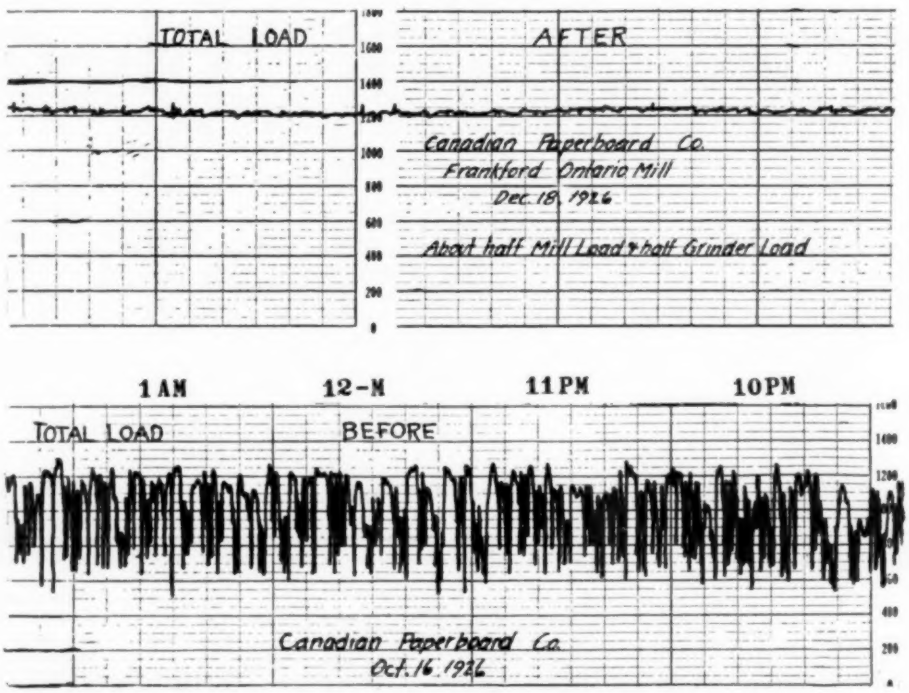


Fig. 7 Total System Load Maintained Constant and Water Power Conserved Through Pulp-Grinder Control

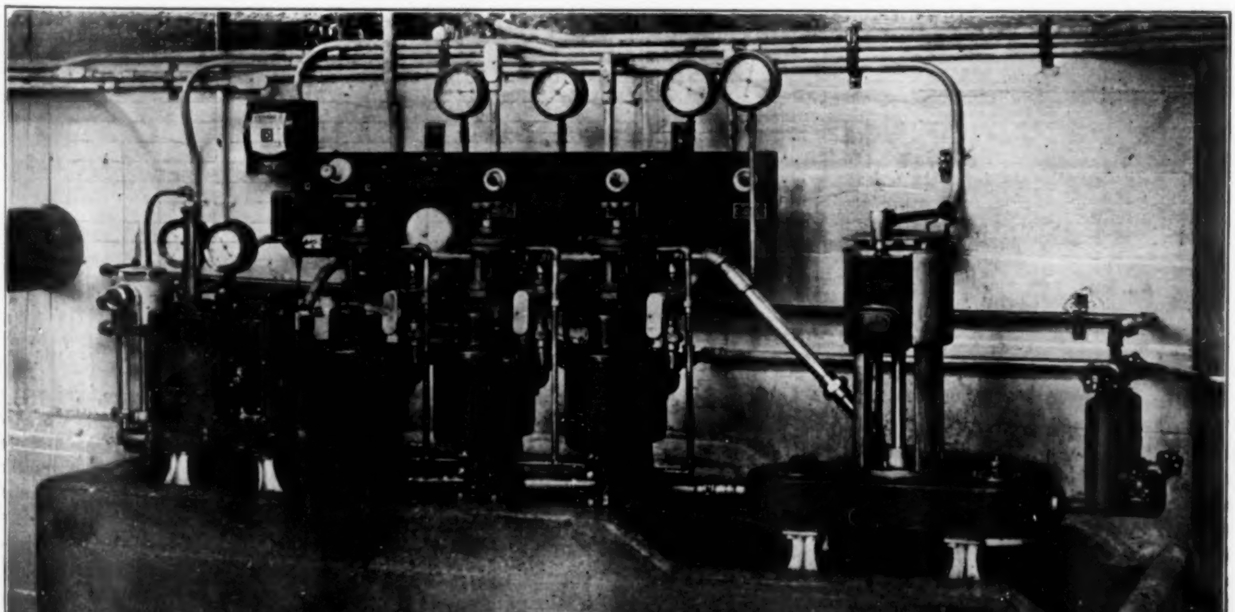

Fig. 8 Typical Installation of Meyer Regulators at Mill of E. B. Eddy Co., Ltd., in Hull, Quebec

(The master regulator is shown at left. The three pilot units with hydraulic load adjusters for the three motors are shown in center. The valve units are installed in grinder room on other side of wall. Pressure-operated switches, signal bell, and switches for load regulators, together with water-pressure gages, are shown in background. At the right is recirculating pump with return tank and make-up water valve by means of which a constant water level is maintained on the suction of the pump.)

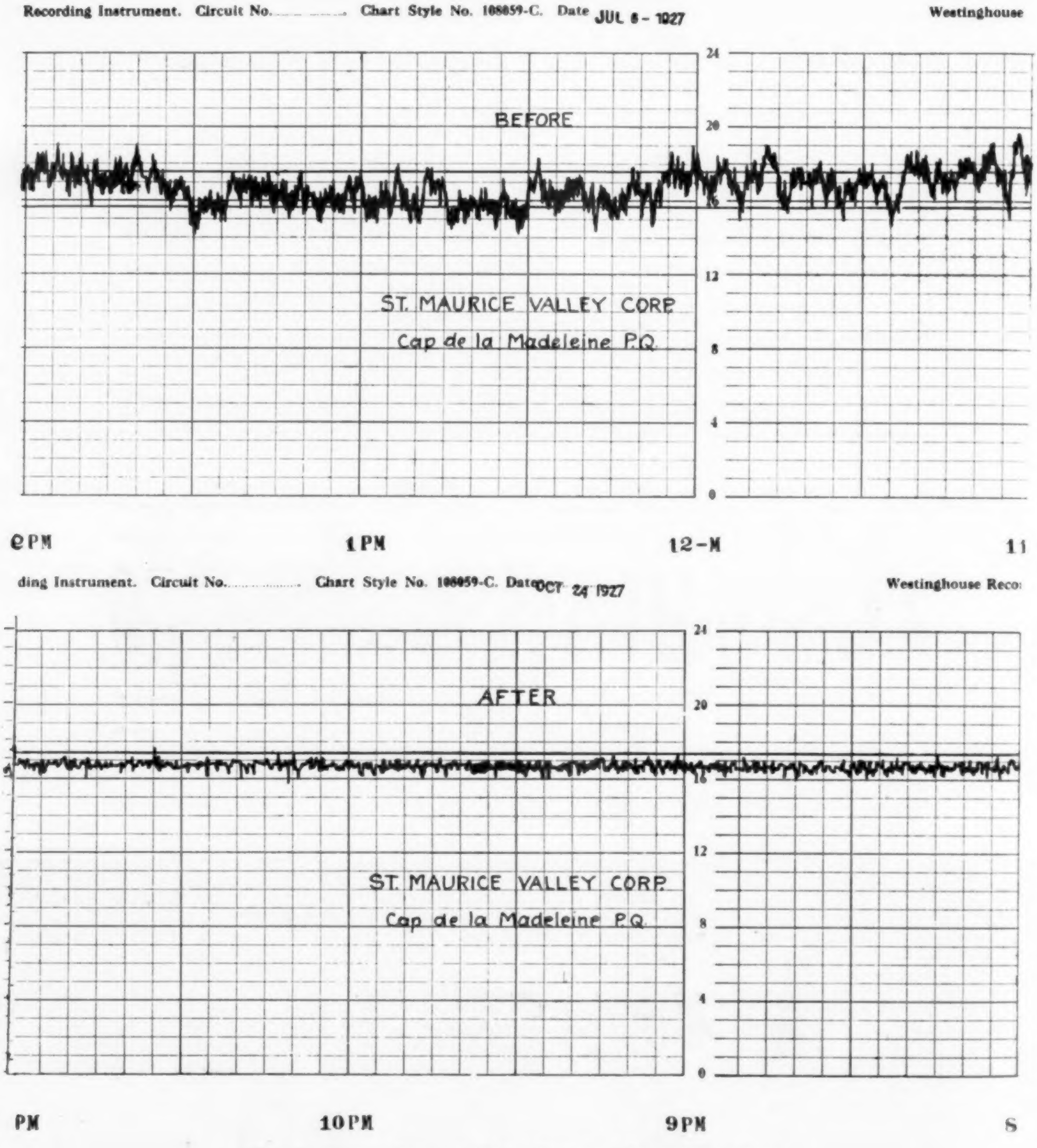


Fig. 9 Charts Showing Total Pulp and Paper Mill Load
(Before and after installation of Meyer system of control.)

### Construction of Master Regulator

The Meyer master regulator, illustrated in Fig. 6, combines all the advantages of the "functional" and "relay" types of mechanism without their disadvantages. The watt element, which measures the total mill load, is opposed by a spring. The tension of the spring is altered to change the total load. An arm on the shaft on the watt element is linked to the lower end of a small pendant tube flexibly connected to a source of water supply furnished by a small centrifugal pump. From the end of the tube issues a flat jet of water. When the load is normal, this jet passes between two knife edges and is led back to the pump. When the load is too high or too low, the tube is pulled to one side or the other by the watt element so that a portion of the jet is intercepted by the corresponding knife edge and deflected down a curved passageway to turn a small waterwheel clockwise or counter-clockwise. The greater the load change, and consequently the greater the portion of the jet which is deflected into the waterwheel, the faster the wheel will turn. It is therefore evident that the response of the mechanism is proportional to the momentary variation of the load from normal. On the other hand, the mechanism makes no response to the numerous severe load kicks of merely a split-second's duration that are characteristic of pulp-grinder loads. Yet there is no dashpot and no damping whatsoever.

By means of a gear train the power of the jet, which is really quite a husky one, is increased and used to adjust a pressure-regulating valve which maintains the required pressure in the hydraulic load adjusters of the individual load regulators, connected to the master regulator by a single line of copper tubing. Each load adjuster has a normal-load, maximum-load, and mini-

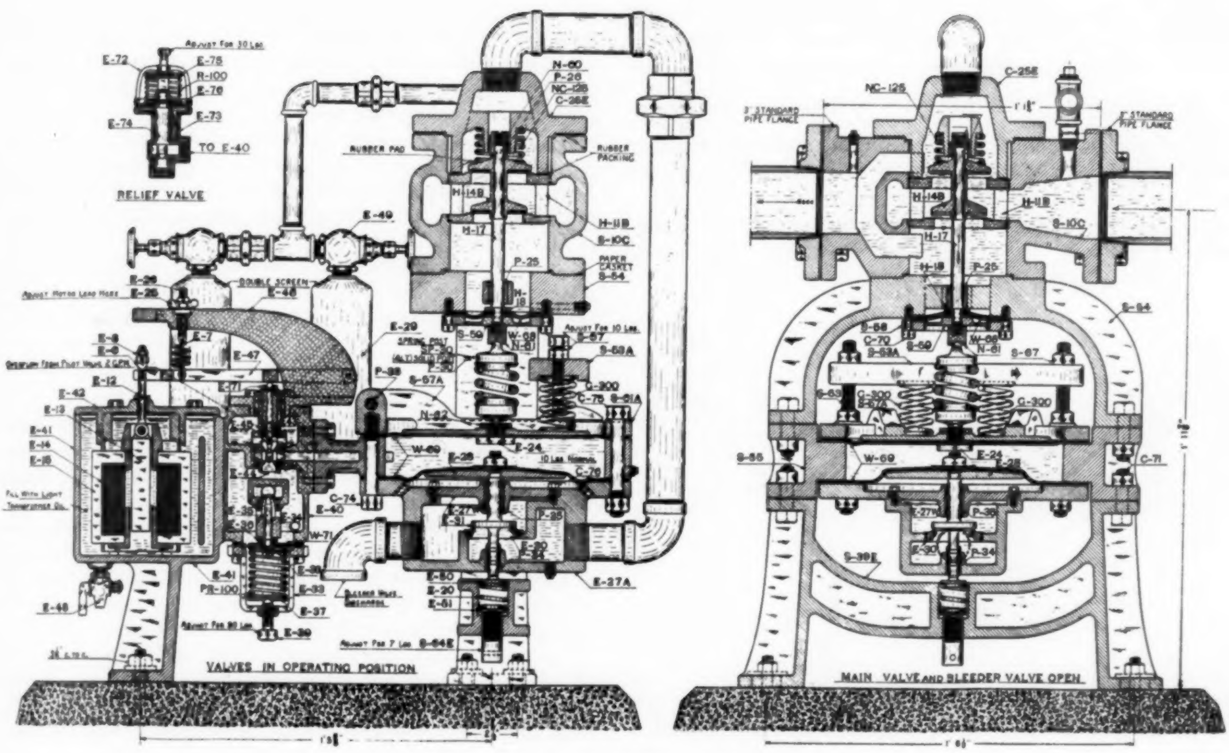


FIG. 10 MEYER LOAD REGULATOR MODEL 25

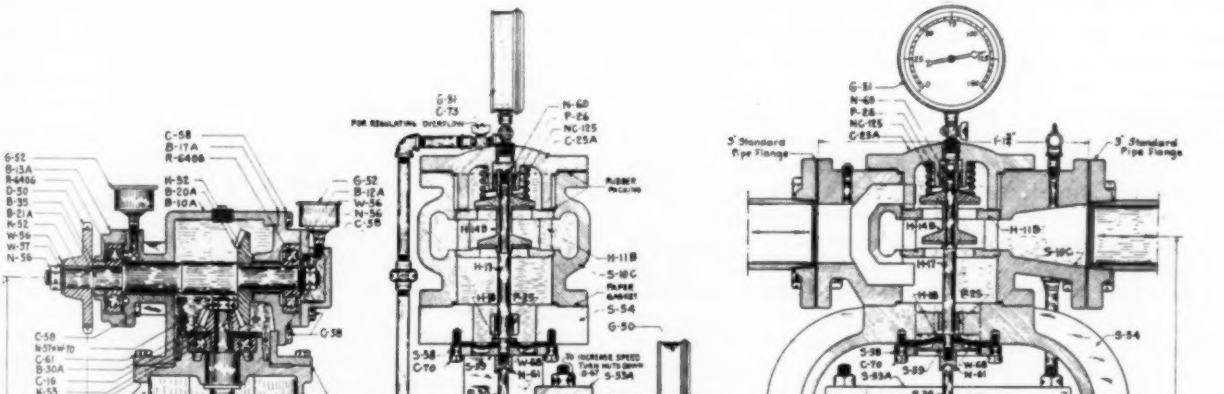


FIG. 11 MEYER PULP-GRINDER GOVERNOR

mum-load setting which can be changed in a moment. In this way different motors may carry different loads and yet share in the load distributions made by the master regulator.

### Conserving Water Power by Pulp-Grinder Control

An interesting application of load control, and one that pays most excellent dividends, is illustrated in Fig. 7. The mill is a

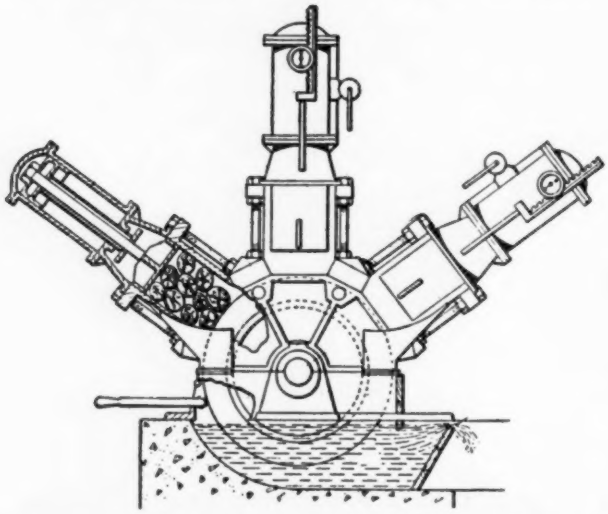

Fig. 12 Typical Three-Pocket, Hand-Fed Pulp Grinder

(The Meyer governor maintains the necessary water pressure in the cylinders back of the pistons to maintain uniform friction load, irrespective of number of pockets in use, binding of wood, or size and character of wood ground. When wood has been practically all ground out of pocket, operator reverses pressure, backing off piston, then refills pocket with wood, turns on water pressure, thus placing pocket under governor control again.)

small one. The power required is supplied by a hydroelectric plant located on a stream where the available water must be utilized or it will waste over the dam. Before regulators were installed, considerable power went to waste, because if an attempt was made to keep the generators fully loaded, and then the mill or grinder load suddenly increased beyond the waterwheel capacity, the frequency would drop and most of the mill operations were handicapped. The chart speaks for itself.

By merely turning a crank on the remote-control apparatus, the power-house operator half a mile from the mill sets the regulator from time to time to maintain more or less total load in accordance with the available water supply. Between such settings the load regulator automatically supplies the mill with all the power required by it and puts the remainder on the grinder motor. The men feeding the grinders change the number of pockets in use from time to time so as to maintain the average grinding pressure desired.

### Improving the Voltage Regulation

The load kicks resulting from the pulling of pockets on grinders, for the purpose of refilling them with wood, are often so severe as to cause undesirable voltage fluctuations. Fig. 4 shows a marked improvement in voltage regulation secured through the installation of Meyer load regulators. The principal reason why such improvement is possible is the unequaled speed of action of these machines. The readjustment required by the pulling of pocket-feeds is usually accomplished in about a second, and the accompanying load kick is absorbed by the inertia of the electric generators.

### Effect of Regulation on the Cost of Paper

By maintaining a higher average load on the grinder motors, a correspondingly larger amount of pulp is produced with the same labor and the same machinery; hence overhead and labor costs are reduced. Experience has also demonstrated that when a uniform friction load is maintained on the pulp grinder a more uniform quality of pulp is produced and the power consumption per ton is reduced about 5 per cent.

By absorbing noon-hour and other reductions in mill load in the grinder room, and by reducing grinder loads at times of heavy demand elsewhere in the system, peaks are avoided, valleys are filled up, and power costs for the entire paper mill are reduced.

The conditions under which paper is made and the principles upon which power charges are based differ so much that it is impossible to predict the average saving which can be effected through pulp-grinder control. Each mill must evaluate its own benefits.

## Discussion

George D. Bearce.[2] It is an old saying that newsprint paper is made in the groundwood mill, and the pulp-grinding equipment and operation are of considerable importance in manufacturing this particular grade of paper.

Wood is a fibrous material of various species and having somewhat dissimilar characteristics. From necessity the mechanical pulp-making process has been carried on largely by rule-of-thumb. The consumption of power was not considered of great importance since each small plant had its own waterpower.

In recent years a closer control of costs as well as an increase in materials, power, and other things has led to a more serious consideration of pulp-grinding methods and control. Many older mills are still using the water-driven pulp grinders, whereas most of the modern plants have adopted the electrical drive with larger units as the most satisfactory method of manufacturing pulp.

In the waterwheel type of grinder the control is especially important. The governor under discussion is widely used and the operating results under regular mill conditions have indicated that this type of equipment is one of the essential controlling factors in the production of groundwood pulp. Since the pulp production of any particular grade is almost in direct proportion to the power required, any increase in the utilization of valuable power means a distinct increase in the production of pulp. Another important feature of this governor is the control of speed and the reduction of danger from revolving the natural sandstones at a dangerous high rate of speed.

In the modern pulp mill where electrical power is used to grind pulp, the development of regulation has been equally important from a cost standpoint. In a majority of cases, the power is purchased on a 5-min. peak-load basis, and any equipment which enables the mill to operate up to but not over its peak load is an important factor in reducing power costs throughout the paper mill. All modern mills watch their load factor very closely, and a number are able to operate at a load factor of 96 to 98 per cent.

The Author. Although most power contracts provide for payments on a peak-load basis, Mr. Bearce's statement that in a majority of cases the power is purchased on a 5-min. peak-load basis may possibly be subject to question. We have furnished equipment to mills paying on the basis of 5-, 15-, 20-, and 30-min. peaks. In one case payment is on the basis of a 20-min. peak, but if that peak is ever exceeded the new peak becomes the basis for payment during the remainder of the life of the contract, which is still over eight years.

The author has tried to present methods of conserving power in the pulp and paper industry through the use of regulating

[2] Engineer, Manufacturing Department, International Paper Company, New York. Mem. A.S.M.E. and Chairman of Paper and Pulp Committee of Printing Industries Division.

equipment on pulp grinders. Large blocks of power are being used directly through waterwheel-driven pulp grinders and indirectly through motor-driven grinders.

For a good many years efforts have been made to build a governor that would control the waterwheel-driven grinder, because, as all know, the waterwheels must run at the right speed in order to produce the amount of power which they are supposed to produce from the water used. For some reason or other these efforts were not successful until the new type of governor was developed which is discussed in this paper. In a general way that governor has made possible, it might be said, an increase in the efficiency of the waterwheels, indirectly through the pulp grinder, of somewhere between 8 and 12 per cent, varying with the conditions under which the power is developed and utilized.

When applied to motor-driven grinders, the new governor has maintained a uniform load on the motors, thereby increasing output and reducing power, labor, and overhead costs, while really improving the quality of pulp produced.

By permitting the master regulator to set the individual governors for more or less grinder load, it has become possible to maintain a substantially uniform total load on the entire pulp and paper mill, thereby reducing the cost of all the power used.

# List of A.S.M.E. Transactions Papers Published Since January 1, 1928

*BELOW is published a complete list of the papers which have appeared in the various sections of Transactions since January 1, 1928, together with references to the issues of "Mechanical Engineering" in which abstracts of them may be found.*

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# Engineering in the Printing Industries

By EDWARD T. MILLER,[1] CHICAGO, ILL.

THE introduction of science in the industries and the creation of new industries as the result of scientific investigation form one of the most interesting chapters in the romance of the modern economic world. Since Watt observed the rattling of the tea-kettle lid by the steam generated in the kettle, and even before, we have had ingenious minds seeking to harness to industry in a practical way the laws that have been discovered by scientists. They worked in an atmosphere of prejudice, superstition, and unbelief, but with each accomplishment the human mind was won away from its old habits of thought. Their efforts were "spotty," but today scarcely any untried project is proposed that the people do not believe some day will be accomplished.

The men who hitch these scientific principles and laws to industry and commerce have come to be known as engineers. Their method of approach to any problem is the scientist's approach. They are trained to find the facts by observation, to apply these facts by experimentation, and to establish correct procedure by calculation.

In the printing industry, speaking broadly, we are concerned with three important groups covering rather well-defined and distinct phases of printing: (1) The supply and conversion of raw materials; (2) the manufacture of tools and equipment for use in the conversion of both raw and semi-finished materials; and (3) the distribution, organization, and operation of printing machines and material and the marketing of the final product.

To a greater or lesser degree each of the industries included in the groups mentioned has made use of the scientist and engineer; at first rather indifferently, but later actually building new industries on their investigations.

The supply and conversion of raw materials, the manufacture of tools and equipment, and their distribution are fields so distinctly different from that of the actual production of printing, though closely related to it, that I am passing over them with but a few general observations. In the other addresses scheduled for this occasion we have two splendid examples of what may be accomplished by engineering in the solution of problems in paper manufacture. There are equal opportunities for a number of other addresses covering other problems in the supply and manufacturing groups of the graphic arts industries; so let us hope that others will be inspired to undertake the research necessary to uncover the material and to present their findings through this division of the A.S.M.E. and other recognized agencies.

I think most of us are willing to admit that there was little engineering or scientific consciousness in any of these industries prior to the appearance of the Hoover report on "Waste in Industry." That report began to awaken such a consciousness, and since that time our steps toward the use of science and the scientific approach—in other words, the employment of the engineer—have been more rapid and better directed.

That part of the Hoover report on "Waste in Industry" referring to the printing industry was a direct challenge to every individual and firm, manager, and employee connected with the graphic arts. The United Typothetae of America was definitely named as responsible for "the management of the industry as a whole" and found itself confronted with a situation compelling it to accept the challenge. The association at that time, representing some five thousand commercial printers in the United States and Canada, particularly in the large printing centers, needed programs of activities that would find expression in direct and indirect services to the various individual members and groups; and the Hoover challenge afforded ample reason for undertaking forward movements in personnel training and in better management methods—for the employment of the engineer to direct the application of science. Up to that time the few things which had been done in the direction of better methods in management occupied only small patches here and there in the whole picture of management, and these were only indifferently coordinated.

The first announcement of "Waste in Industry" in 1921 attracted wide attention among the commercial printers group. A liberal portion of the report covering the printing industry was published in *Typothetae Bulletin*, and the Executive Council invited John H. Williams, engineer-author of the report, to address the annual convention. Inspired by all this the general office staff of Typothetae advocated during the fall and winter of 1921 and 1922 the establishment of an engineering department at the general offices, and the executive officers adopted a resolution assuming a sympathetic attitude toward all engineering efforts in connection with the printing industry. In the meanwhile numerous inquiries began pouring in from members for assistance in their production problems, and to the department of research was assigned the duty of rendering such assistance.

To many of the laymen at that time the very word engineering was little understood, and in scores of instances an engineer was thought to be some kind of an exalted janitor who looked after the electric lights, the steam-heating radiators, the repair of windows, or the furnishing of extra keys for the doors. But a series of well-selected articles in the association's journal, referring to the application of scientific principles in printing as really the application of engineering, began to develop no inconsiderable interest in the broad scope of engineering as it might be applied to printing. Of course there was much groping in the dark for the door that would lead the industry out into the light. There were almost as many different conceptions of what engineering in its broadest sense is as there were individuals. Happily we found among managers of printing plants a score or more of men whose early education and training had been along engineering lines, and these men materially assisted in steadying the course along which we were steering and in shaping the growing interest. In the writings of these men at that time it is interesting to note how close together were their definitions and their opinions as to how engineering can be applied to the printing industry.

Matters finally progressed to such a point that our executive council appointed a committee on engineering to study the whole question of engineering as it might be applied to the industry, and Typothetae was reminded that it could not take its real place in "the management of the industry as a whole" until it could bring to bear in a scientific way the experiences of the industry in matters affecting finance, production, marketing, human relations, and matériel.

Gradually there has begun to grow a consciousness among the membership that presiding over each individual member as well

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as the industry as a whole there is one masterful fountain head which we call management, and to it are bound all principles of truth, all scientific knowledge, and all righteous human relations with inflexible sinews, while engineering is the medium through which these laws are interpreted to management.

So closely indeed are management and engineering and industry bound together that there have grown up such expressions as "management engineering," "industrial management," "industrial engineering," all more or less synonymous but all describing the application of the laws governing the engineer and the scientist to management of industry.

When our committee began studying the subject of engineering as applied to printing, in its broad way and under these synonymous terms, a realization came to them that the United Typothetae of America was to some degree attempting to cover the field of management engineering. It was said at the time, "The trade association which so far studies the problems of its individual members as to recognize in them merely problems of engineering and then prescribes proper methods and operations based on scientific knowledge and principles is most certainly engaged in a work that is coming to be known as industrial engineering."

In my report to the executive council in June, 1922, I observed that the United Typothetae of America had progressed rather well in providing service in accounting, cost finding, advertising and sales, but that in the field of production engineering only a limited number of services, such as studies in industrial relationships, production standards, simplification and standardization, and a study of classification of operations, had been set up. I ventured the prophecy that the time was not far distant when we must coordinate all of the phases and elements of production engineering so as to give as complete service in that direction as we were giving in the field of administration and finance, and in the field of advertising, sales, and distribution. I am happy to say that since this forecast was made our management engineering services have not only increased in number, but have been rather well rounded out and are beginning to register real results among our members; but we have done just enough of it to see that we are only at the threshhold of tremendous opportunities and equally tremendous obligations.

It was not until late in 1923 that the whole engineering program was classified and set down in outline form, and it is interesting at this time to note the classification then used. Briefly and in substance it was as follows:

1 Fundamental statistical and experimental research
2 Engineering as it pertains to administration and finance
3 Engineering as it pertains to personnel
4 Engineering as it pertains to matériel
5 Engineering as it pertains to production
6 Engineering as it pertains to marketing.

A development of this outline, it may readily be seen, will provide for each of the four general phases in every commercial printing business; namely, finance and accounting, production, marketing, and personnel training and relationships.

The staff at the general offices began gradually to mold all Typothetae activities and services to this general classification. Standing committees were altered and even consolidated in order to prevent overlapping functions, and all were better coordinated. The departments at the general offices were rearranged and reorganized to parallel this general classification. At present we have a department of finance and accounting, a department of production management, a department of marketing, and a department of education, all backed and supplemented by the bureau of research. In addition to these there are of course the necessary administrative and executive departments and offices. The men in these various departments are specialists trained in their particular lines. The department of production management is the one no doubt of most interest to this division of the A.S.M.E. in that all production-engineering activities are centered in this department. The men themselves are engineers, and the head of the department is a member of this Society. He thinks and acts in terms of engineering, and the department is conducted largely for the purpose of giving engineering counsel and advice not only to the administration of the association but to our members in their daily problems in production.

This department heads up the work of the engineering committee and coordinates that committee's work with the work of the committee on simplification and standardization, the management and research committee, and of a number of minor special committees. Perhaps the most noteworthy achievement of the department of a permanent character has been its accumulation over a period of years and the final publication at a considerable expenditure of the Typothetae Average Production Records—an engineers loose-leaf manual, if you please—averaging the records of production in practically all of the operations of the printing plant. The data on which the records are based were accumulated from original sources and thousands of actual jobs of printing that had gone through plants. It furnishes to the estimator the only known standards of production in the various operations. It furnishes the cost accountant with a reliable measuring stick with which to check costs. It furnishes the sales manager with definite specifications as to the character of printing he proposes to furnish his customer. To the wide-awake printer who takes advantage of all such aids it is a compendium of information equal to any engineer's handbook or manual. It is the basis for job layouts, analyses, and estimates, and it has proved of almost uncanny accuracy in scores and scores of instances. Though only an accumulation of average records the book seems to overawe many to whom it would be most useful. Craftsmen and production executives therefore all have to be trained into the use of it. The younger men in the industry, however, take it up readily—a hopeful aspect of the situation.

More recently the department of production management in cooperation with the committee on engineering has formulated a program covering not only the scope of the productive branch of the printing business but laying out the work of the department for some time ahead. In outlining the scope of the field of production management the fullest consideration has been given to the physical printing plant as a machine for producing printing; to the regular and special printing processes; to the analysis of the functions, methods, and purposes of each job in the producing branch; to the selection, training, handling, compensation, methods of work, and working conditions of the personnel; and to records, forms, and reports used in production management. The work of the department in carrying out this program is outlined under two main divisions; (1) The collection of data on each of the phases of production; (2) the organization of these data into a form usable by the membership and the presentation of the information in regard to it, together with instructions in its purpose and use. It is a significant fact that trade associations in their endeavor to serve their members often expend their energy on tasks that are expedient rather than fundamental, and afterward the fundamental phase of the work becomes so apparent that it is taken up and finally fitted into the picture. Therefore, this program is designed largely to coordinate the work that has been done with the work that is yet to be done so that the tasks that have been accomplished largely on the ground of expediency may be fitted in with those fundamental things that are yet to be accomplished.

Engineering societies such as the A.S.M.E. are needed to cooperate with trade associations and to assist them to bring their activities and services into harmony with the engineering program. The engineering societies can assist very materially in building the engineering program, particularly in production. Engineers will find a new and comparatively little occupied field in serving trade associations in this newer phase of their work. Particularly is this true in the case of engineers who have broadened out in their studies and experiences so as to cover the whole gamut of industrial activities, men whom we are now beginning to call "industrial engineers."

It is gratifying to me to see the activity of the A.S.M.E. in this respect, and I am pleased to serve as a member of your divisional Committee on Research and Survey. Recently I suggested to the chairman of that committee[2] an outline of a program that might well be followed during the next year or so. In my outline I used the engineering approach; that is, I suggested that the first thing to do is to find out what are the actual conditions, what are the facts in regard to research in the graphic arts. When we shall have determined that, then I believe we should gather them together and catalog them, after which we can work out or determine the scope or the phase of research that would prove of the greatest benefit to all industries involved. I suggested briefly the following outline: (1) Compile a complete list of all agencies, domestic and foreign, engaged in printing trades research; (2) classify research work now being done, and ascertain its extent in machinery, systems, and processes; (3) catalog all activities to date showing scope of work already accomplished as a guide to what problems to take up first and which ones already under way to complete; (4) determine the exact scope of the activities of research committees and research departments—whether they are to comprise purely production problems or to include problems of finance, marketing, etc.; (5) work out a functional head of all these research activities to assemble all data, classify these data, disseminate information to the members, and solicit papers and treatises on special subjects.

In the brief time at my disposal it has been possible to refer only to some of Typothetae's efforts toward introducing engineering principles to industry and to outline briefly what may yet be accomplished, not only by it but by the other associations and societies representing other groups in the graphic arts. A great deal of what has already been accomplished is good, but much of it is necessarily indifferent and of little importance, because laymen are apt to undertake such things with a woeful lack of the sense of proportion. Better things are expected of engineers, and if all groups of the printing industries were to cooperate and through such cooperation set up a plan of coordination of our efforts, in comparatively a short time we should have built up a vast fund of practical, technical, and scientific information that will be of immeasurable benefit to all interested. What nobler task can be set up for a society such as the A.S.M.E. and for trade associations such as the United Typothetae of America and the other associations in the graphic arts? Where could there be a program whose objectives are more fundamental and more certain of bringing prosperity to our industries and better services to the public? It seems to me that engineering brings a challenge to the industries, and that the industries will find their greatest advancement by accepting the challenge.

[2] Arthur C. Jewett, Director, College of Industries, Carnegie Institute of Technology, Pittsburgh, Pa. Mem. A.S.M.E.

# The Standardization of Colored Printing Inks and Its Advantages

## Confusion Exists in the Color Field at Present, as Discussions and Instructions Regarding Color Have No Common Basis or Viewpoint

By TAYLOR W. ANSTEAD,[1] CINCINNATI, OHIO

*The author discusses briefly the materials entering into the manufacture of printing ink. Since the pigments used in their manufacture exhibit the widest variations, standardization of colored inks is really the standardization of the pigments involved. Various proposed methods of standardization are considered, and it is hoped that out of their discussion some practical system will result that will do away with the confusion at present enveloping the subject.*

The purpose of this paper is to discuss briefly the confusion existing in the colored-ink field and the need for some sort of standardization so that all discussions regarding color may have a common viewpoint.

Before considering the question of the standardization of colored inks, it might be well to consider the materials that go to make up a printing ink.

### Materials Used in Making Printing Inks

Printing ink consists essentially of two parts, the vehicle or varnish, and the pigment or dry color. While in order to get certain desired working qualities various compounds are often added, yet, as stated, the two essentials are varnish and pigment.

Varnishes for high-grade printing ink are made almost exclusively from linseed oil. This oil adapts itself readily to use as a vehicle for two reasons: first, its viscosity can be increased from that of water to that of molasses taffy; second, linseed oil will absorb oxygen from the air and form a hard film or "dry," as the reaction is called technically.

The "bodying" of linseed oil is carried on by heating it in a copper kettle over an open flame, the resulting body depending on the temperature and time of heating. As the free-acid content of the linseed oil increases with its viscosity, it is necessary to start with an oil of minimum acidity so that the final acidity will be kept as low as possible, otherwise the varnish may react with some of the pigments used in the ink. Color and odor are also two factors entering into the choice of linseed oil.

The drying of linseed-oil varnish by the absorption of, and combination with, oxygen from the air is a true chemical process as opposed to drying by absorption as exemplified by the newspaper where a porous paper absorbs the ink. This chemical action of "drying" may be hastened by the introduction into the ink of very small quantities of substances known as "driers." These driers are resinates, linoleates, or acetates of cobalt, lead, or manganese, and act as catalysts.

Depending on conditions of price, character of pigment, and intended use, mineral oil and rosin oil are often used alone or in conjunction with linseed-oil varnishes, but for the very best type of printing, linseed is to be recommended.

Prior to, say, fifty years ago, coloring matters for printing ink were of mineral or vegetable derivation. Carbon black, bone black, English vermilion (mercuric sulphide), ochers, umbers, siennas, ultramarine blue, iron blues, chrome yellows, and chrome greens were of mineral origin, and indigo blue and madder lake of vegetable origin.

The discovery of the first coal-tar dye by Perkin in 1854, the subsequent discovery of many more and the application of many of these to pigment making, beginning in about the year 1880, led to a new era in printing. While of course most of the old colors are still used to some extent—some of them like carbon black, iron blues, and chrome yellows in enormous quantities—they have been supplanted and the field of color greatly enlarged by the use of pigments from organic dyes.

Three of the main characteristics of the organic pigments have been their good working qualities, their tinctorial power, and their purity of tone, the first allowing for greater speed in the printing press, and the last two for the development of special processes such as the offset process and photolithography.

### How Pigments Are Made From Coal-Tar Dyes

It might be of interest here to consider briefly just how the pigments are made from coal-tar dyes. One class of dye comes on the market in a water-soluble form, usually as the sodium salt of the dye. Naturally, being water-soluble, it is useless as a pigment, especially for lithographic or offset work where water is used. Consequently it must be rendered insoluble, usually by the addition of barium chloride. Expressed by chemical equation this reaction takes place:

$$\underset{\text{(Water-soluble)}}{2\text{Na (Dye radical)}} + \text{BaCl}_2 \longrightarrow \underset{\text{(Water-insoluble)}}{\text{Ba (Dye radical)}_2} + 2\ \text{NaCl}$$

As variants, salts of calcium or lead are sometimes used to obtain different shades of pigments from the same dye.

The precipitated dye if to be used as a "toner" or 100 per cent color is washed and filtered and then dried in a drying oven. It is then ground to a powder. If the color is to be of reduced strength some white such as blanc fixe (barium sulphate) or alumina hydrate is added to the precipitated barium lake and the resulting color washed, filtered, dried, and powdered.

Several important pigment dyes come on the market as insoluble sodium salts, but on being boiled with barium, the latter metal replaces the sodium, producing the same result as if the dye were soluble.

Another type of pigment is produced directly from the dye-forming elements or "intermediates." A familiar example of this type is para red, made by combining the yellow paranitraniline with gray beta naphthol to produce para red.

In making the finished printing ink the powdered dry color and the varnish in a predetermined ratio are given a preliminary mixing in a pony mixer in order to wet the color with the varnish. The mixture is then sent to the mill room and ground on a three-roll mill until the ink is pronounced finished by the tester. The number of passes over a mill necessary to grind an ink varies with the color. Some colors only take two or three runs, while others require seven or eight.

Of all the ingredients going into printing ink the pigments exist in the widest variety, and therefore a discussion of standardization of printing ink is really a discussion of the standardization of colored pigments suitable for inks.

[1] Chief Chemist, Dry Color Division, Ault & Wiborg Co.

Presented at the First National Meeting of the A.S.M.E. Printing Industries Division, Rochester, N. Y., November 8 and 9, 1928.

The term "standardization" is not very definite, and various constructions can be put upon it, namely,

1 Standardization of inks for process work in yellow, red, blue, and black.
2 Adoption of a standard nomenclature for colors.
3 Simplification and standardization of colors, and
4 Standardization by measurement.

### Standardization of Inks for Process Work

Let us consider the first case, that of standardization of inks for process work. Successful selling through printed matter depends upon faithful reproduction of the original idea. An advertiser calls upon one or more artists to submit their ideas for a colored advertisement to run, let us say, in a great national publication. He chooses one that appeals to him, and plates are then made true to color. The publisher now receives the proofs, and the advertiser awaits publication with the joyful feeling that many sales will result from the attractive advertisement.

When the publication comes out the advertiser is sometimes terribly disappointed in that the whole color scheme has been lost. Why? Because while the artist has free rein in his choice of colors, the publisher is held down by the limitations of his inks. He selects what he thinks is a happy medium to do justice to the color scheme, but often the results are anything but satisfactory.

Of course, the only remedy for such a situation is standardization of a series of colors to be used by the artist, the photoengraver, and the printer. The artist would then select from a chart of these standards the color combinations to make his painting. The photoengraver would in turn use the same standard in the form of printing ink in making his proof, and finally the printer would be supplied with progressive proofs by the photoengraver with the particular standard ink used in each case, so that there could be no question as to the color wanted.

It is believed that in this way the results obtained in the original picture by the artist would be carried on through to the final advertisement.

Some printing-ink houses do put out charts showing the color combinations that can be obtained through the use of their standard-process inks, but of course there is no unanimity on the subject, each ink maker having his own ideas. Some central organization such as the National Association of Printing Ink Makers or the Lithographic Research Foundation at the University of Cincinnati, might develop a standard chart that printing-ink makers would follow, and thus assure the printers standard colors no matter from whom he buys his inks.

The opponents of this plan point out that such a standardization would produce stagnation. There would be no incentive to bring forth new color combinations because these would be deviations from the standard. In order, of course, to prevent this the colors used as a basis for the chart would have to have a great variety, which brings us back to the multiplicity of colors obtaining now.

### Adoption of a Standard Nomenclature for Colors

The second case of standardization is the adoption of a standard nomenclature for colors. Let us consider just a few names given to colors and see how close to a standard they run. There is primrose yellow for one instance. One dry-color maker puts out several shades of light yellow he calls primrose, one of which will match another maker's "lemon yellow." Another maker has a yellow with a high gloss that he calls primrose that is not of the same character as the first primrose in question. Then there are cerulean blues that are almost greens, and others that are a sky-blue. The author has seen colors called crimson in a range from a fire red to a deep magenta. Then there are geranium lakes which probably match some other maker's dahlia red, and so on and so on. In most cases the colors are named fancifully like Pullman cars or collars. The author knows, for he has been guilty of such enormities himself.

There might have been some excuse for this romantic nomenclature when the organic lake industry was young and colors were named so that no idea could be had of their chemical composition, but in these days when the color man will tell the ink maker into just what class a certain pigment falls, there is no necessity for the wide variety of names.

The colors that we use in our Cincinnati plant are these: Reds, 45; yellows, 13; browns, 4; oranges, 8; blues, 11; blacks, 4; greens, 10; purples, 8; whites, 11. This makes a total of 114 different pigments, so that really the standardization of ink in printing comes back to the standardization of the various colors made from it.

Some system of standardized naming ought to be adopted such as the "Standard Color Card of America" issued by the Textile Color Card Association of the U. S., Inc. On this card are dyed pieces of silk showing such colors as turquoise, ocean green, scarlet, geranium, etc., so that a very clear conception is had of just what each color is.

### Simplification and Standardization of Colors

The third case of standardization is simplification. There are probably far too many colors that are mutually replaceable or that could be obtained by mixing other colors. The chrome yellows are a case in point. They run all the way from the very light acid yellow commonly known as "canary" to the very orange basic yellow known as deep orange chrome or similarly designated. Tentative steps toward simplification have been taken by a committee appointed by the Federated Varnish Production Clubs. It was agreed by this committee to start first with this chrome yellow series. It has been estimated that there are two hundred distinct shades of chrome yellow put out by the various manufacturers of dry color. It is proposed that this number be reduced to twelve, varying from the light yellow to the orange. The committee feels that with these shades any desired combination can be obtained.

From the yellows to the iron blues and chrome greens is a fairly simple step, but with the wide variety of reds the difficulties might prove to be insurmountable. However, it will be extremely interesting to watch the progress of this committee. The Department of Commerce has set out to standardize in industry and has already, it is reported, reduced greatly the number of varieties of bricks and dishes made, so it is not improbable that some progress could be made along the same lines in colors, not only in the paint and varnish industry but also in the printing-ink field.

### Standardization of Colors by Measurement

Then finally in our consideration of the standardization of colors we come to standardization by measurement. The principle of the various schemes evolved is some index for each color determined in various ways, depending on the method used. For instance, one method is by spectrometric measurement of light reflected from a printed sheet of the color. The reflected light is broken down by the prism into its components, which are given a scale value. Therefore, by reproducing these values by a mixture of colors representing the scale "readings," one should be able to match exactly the original colored proof.

On the surface this method appears very logical and the author is in no position to condemn it of his own knowledge, but he has been informed that transmitted light, such as light passing through the solution of a dye, is accurately broken up, but reflected light, such as from a printed proof, does not give true values as not all the light rays are reflected but some are absorbed.

This lack of total reflection gives confusing results, and one incident was told in which a color was analyzed in one part of the country and the graphic results sent to a branch in another, but when it was attempted to duplicate the color the results were anything but identical.

While probably no one of these various methods of standardization may ever be adopted in its entirety, at least they are gropings toward some adequate system whereby artists, printers, pigment, and printing-ink makers, and users of color generally would be in agreement upon the subject of color.

One writer has even gone so far as to dream that a system of notation could be adopted which one could read as if a sheet of music, and reproduce the color, as the inspiration of a musician is reproduced on a musical instrument.

Certainly language alone is not sufficient to describe color, as witness this letter of a master stylist, Robert Louis Stevenson, from Samoa on October 8, 1892, to a friend of his in London:

> Perhaps in the same way it might amuse you to send us any pattern of wall paper that might strike you as cheap, pretty, and suitable for a room in a hot and extremely bright climate. It should be borne in mind that our climate can be extremely dark too. Our sitting room is to be in varnished wood. The room I have particularly in mind is a sort of bed and sitting room, pretty large, lit on three sides, and the colors in favor of its proprietor at present is a topazy yellow. But then with what colors to relieve it? For a little work-room of my own at the back, I should rather like to see some patterns of unglossy—well, I'll be hanged if I can describe this red—it's not Turkish and it's not Roman and it's not Indian, but it seems to partake of the two last, and yet it can't be either of them because it ought to be able to go with vermilion. Ah, what a tangled web we weave—anyway, with what brains you have left choose one and send me some—many—patterns of this exact shade.[2]

It might be interesting, as a study in color standardization to know just what Stevenson's friend did send him.

In conclusion, the author wishes to say that he has nothing definite to offer as a system for color standardization, but hopes that out of discussion of the subject some practical system may result.

## Discussion

Joseph M. Farrell.[3] I have heard so much about standardization for the past two years that I just about dream it, and this is the first time that I have listened to someone talk from an inkmaker's point of view offering something constructive. I cannot talk to you in theory, but I can give you a picture of the advertising business as it is today and tell you exactly where standardization stands. I do not know of anything that is more of interest in the production field of printing today or to the advertising trade than the standardization of colors. Some years ago the American Institute of Graphic Arts had a standardization committee. It worked on some colors, and they had some very able men on the committee, who definitely decided on some very excellent colors.

I am the buyer for a large advertising agency. When we work on a four-color advertisement, we proceed about as follows: We receive an art copy, and the advertisement is scheduled to appear in eleven or twelve of the largest circulated magazines in this country. The publisher tells us that we must give him original plates, and so we order certain plates, and the publisher tells us that we must use certain plates. Now, I believe that the advertising company in cooperating with the publisher and the engraver is tied down to all these things, which is a good thing as I see it. When we get the first set of plates, which is the first set which we would submit to our clients, a good deal of time and thought have been spent on them. This one set of plates would be what we would call satisfactory, but there might be only three out of ten that we would really be satisfied with. When we get to some other colors, a blue or green would be so entirely different that we could get nowhere near to our engraver; and I am sure that if you look at any of the art advertisements as they are today, you will understand what I am saying. We would go to the publisher and almost beg him to let us use another color because the engraver could not get a good job; and in some cases we would be successful, but it would go into other magazines and you would have a very unsatisfactory job.

Today I believe that standardization has progressed greatly. It is not 100 per cent right, but it has made good progress. Two years ago we went before the engravers and they approved our work, and then the advertising agency and our committee of the advertising agents association took up the great task of selling standardization to the publishers. Nobody else seemed to be able to do it, but we sat down and tried to convince them that it was necessary, and we also decided that the way to do it was to get the individual publisher's opinion. I have worked with 165 publishers of general magazines and 200 publishers of trade papers, and except in a very few instances I do not know of any case where standardization was not received as a great work. I think I am very conservative, and I hope the company I represent is conservative, and I think that if there was anything in standardization that was going to physically hurt our product we would never be for it.

For a year and a half the color work in our company's plant has gone out with these standard colors, and we do not have the problem any more of going to the publishers and asking them to use some other color; so this is what I mean by saying that I am sure that we are making some headway. I know that a great many advertising agencies are cooperating with each other on the standard colors.

Today practically all of the large magazines will accept our progressive policy in respect to our colors. Most of the old magazines are still on the old policy, but I think for good business reasons it is good policy to give the publisher what he wants, and that is all we are trying to do.

Comparing the advertisements or the advertising that comes through today with the advertising that went through a year and a half ago, it shows much improvement. We have the same shades of color, and we have certain inkmakers, and the engravers tell us they must use their ink, so that we have to check up. Now the inkmaker gives the same shade of ink all around. I think that is where the author has hit a vital point. We endeavor to have a uniform standardization of ink all around and to be as near right as we can make it, and I think that this is the kind of constructive work that inkmakers can do to cooperate with each other—work to turn out a uniform shade of color.

Standardization has done a lot of good. When we get one set of plates it helps to check the others. Now, I think that it is wrong to do it any other way, because the engraver sells the proof with a certain ink to an agency, and he gives it to the publisher, and somebody from Chicago sends in the ad with one color, and somebody from New York sends in another color, and from the Pacific Coast in another color, and then they start compromising, and there is trouble. There are always a certain number of printing superintendents and engravers that throw cold water upon standardization for some reason. On the other hand, we have dealt with a large number of magazine publishers and printers of magazines, and their remarks and their efforts are encouraging us to realize that standardization is the right thing, if each person goes about it in the right way and takes the interest in it that he should.

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[2] "Vailima Letters," New York, Scribners, 1901.

[3] Chairman, Mechanical Production Department, American Association of Advertising Agents, New York, N. Y.

My own experience is that we have had no particular difficulty with reproducing our copy in certain colors. If by chance it turns out that we have an unusual piece of art from the artist so that we need a little different blue, I would not hesitate to go to our publisher and ask him if it is not possible to use that color. Now I am talking against my own people as much as anybody else, and against photoengravers, and no photoengraver should use any other color than that specified by the publisher. If they do use another color, they should only do so after requesting the publisher's consent.

Just to give you a certain example: The Curtis Publishing Company said to us: "I hope you can put over standardization, but we are a little dubious," and they specified that the photoengraver must use Levy inks and proving plates. They went to work with Levy inks and worked out that 1558, 1559, and 1560 were the inks that matched the colors that we wanted. Now we have notified every engraver that in making plates for the Curtis Publishing Company they should use Levy inks 1558, 1559, and 1560. If our engraver sends in anything else, we return it and say, "You must meet the requirements of the Curtis Publishing Company; no one should use other colors except the ones specified or by permission of the publishers," and we are checking up on our photoengravers.

I believe in this organization work which we have done with the publishers. The part that will help out is that if future work and technical work can be done among the ink manufacturers, it will assist us to do our work with the publishers.

Randolph T. Ode.[4] We have seen good results in using proper pigments in making the original, but in our case where we have pictures coming from all over the world, from the greatest painters of the world, should we attempt to secure standardization we would fall down ridiculously; in fact, it would be impossible. I think the statement as to what is the best way to handle the situation—that is, through publishers getting the engravers to use the inks that the publishers are going to use—is the only logical way to do it. Furthermore, if the publishers and the ink manufacturers will come together in connection with this matter of standardization and find out what they are talking about, that is an equally important step. The problem is just the same in lithography as it is in relief work, a very complex one, and it is becoming more so than ever before. Lithography today has come down from a multicolor proposition to that of a four- or five-color one.

There is a help in color work of which all printers do not take advantage, and that is to place on the printing cylinders of the press circumferentially the same picture, so that by varying the amount of ink at each ink fountain a balance of all the values may be secured and thus a much better final print be obtained. Two different pictures placed circumferentially on the cylinders do not readily permit this adjustment, for a light amount of a color required for one picture may not be suitable to the other.

A. J. Newton.[5] The inkmakers are the most reactionary "standpatters" I know of. We have had Mr. Priest, one of the great color experts in this country; we have Mr. L. A. Jones.

Now, the first man to consider is the man who pays for the advertisement. Supposing you have a big advertisement, such as the Proctor & Gamble advertisement, in 25 different publications. They pay an enormous sum for one picture, and you send out these advertisements, and you get different results in your color photography; not one of them is like the original in colors. Why not? Because all these publishers are using different inks, and not one of these advertisements is like the other, and not one of these inks is like the other. Each one says, "I am going to use my ink;" and they are never satisfied, and least of all the man who pays for the advertisement, the customer—he is the man who should be pleased in the first place. The publisher of "Life" magazine would bring up his magazine and show the illustrations they have put out and thought were fine; then they put the same advertisement in the "Woman's Home Companion" or the "Saturday Evening Post," and they are as different as chalk and cheese. Now, that does not satisfy the man who is paying for the advertisement. If he is paying for the advertisement, he wants it to appear as he gave it to the engraver; and it is absolutely impossible while the engraver is using one sort of ink, the publisher another, and while each publisher is using a different sort of ink.

The customer says, "We will not buy this space in your magazine unless we can get standard colors." Of course, it is better to use a standard set of colors. Each inkmaker uses a grade of ink of his own, and he says, "Now, that is my red, and this is my blue, and this is my yellow;" and they each use different shades. And so we get together with an advertising agency, and most of them will specify a standard set of color inks that have been agreed to by the advertising publishers and have been agreed to by the inkmakers, and they will correspond. There is some sense to that, of course, but it is difficult to alter your standards.

A man with an advertisement in 20 different magazines will get approximately equal results from every one. A couple of years ago this was not the case; they all were entirely different—some perfectly ghastly. I think we shall not only get things alike, but will improve our standards greatly. I am very pleased with the progress we have made. We have had opposition from everybody, especially from the engravers. The engraver says that he is going to use his ink, and no matter how he got it he does not care about the plates after they leave his hands. Now, you have the same problem with the publishers. They say, "I have been using these inks for years, and they are good enough, and my father used them before me, and they are good enough for me;" and if they will not conform to what he wants, he says that he will buy from someone else.

With regard to forming these standards, of course there has been a lot of work done on standardization, and the reason we have not made better progress is the inertia of the people most concerned. They will not take the trouble to understand or think about the subject or work it out. Of course you cannot do away with fashionable methods, but that has nothing whatever to do with scientific standards of color, if you use scientific methods of doing it. The author said he found that the results from the photometer do not correspond. Of course, it takes time; it takes practice; it takes experience to use a scientific instrument; and if the apparatus were used properly, then the results would be the same. If a man uses a photometer the first time, he does not read it so accurately, but when he gets used to it, his results in using the instrument here in New York are the same as in California; and if he gets the same result and the same shade of color from the transmitted light and reflected light, then the shades are the same. There is quite a difference in shade if you print a thing on a transparent medium and also on a perfectly white medium, and the same thing can be measured, recorded, imitated, and copied, and is perfectly definite.

A color has three components: hue—that is, the actual shade; saturation—that is the amount of density or intensity of the color; brightness, or brilliancy of the color. Munsell has another system which has the same three components. He calls them hue, which is the shade; chromo, the intensity; and the degree of that particular hue.

[4] Secretary, Providence Lithograph Company, Providence, R. I. Mem. A.S.M.E.

[5] Engineering Department, Eastman Kodak Company, Rochester, N. Y.

You can take it in a scientific way, but it all can be done and it should be done, and I figure that every inkmaker should see that the ink corresponds to the color. It is absolutely necessary that the complementary color he uses should be a yellow, a yellow of a certain shade, which absorbs all the blue and at the same time reflects all the green and the red. The trouble is that you cannot get him to see it at all. The ink that you use for the green record should be exactly complementary to that green record; that is, a magenta, a color which is minus green, a color which absorbs all the green, and at the same time reflects the red and the blue. It has been very difficult to get the inkmaker to see that. It is very difficult to get the absolutely ideal theoretical colors, but we can go, and indeed we have gone, a great deal farther than they used to go a good many years ago. And now we are getting the colors very much nearer what we want, and they are more or less alike from the various inkmakers who have been approached in this matter. So we are getting some improvement. When we get these steps carried out, it will be the greatest economy and satisfaction to have anything to do with the production of ink and with the use of color reproduction. I am heartily in favor of color standardization.

Charles L. Garner.[6] After listening to Mr. Newton's talk on the standardization of ink, I want to say that some firms that I know have adopted a uniform art standard, as adopted by this standardization committee. In support of that statement let me say that recently we received an order from a local house, in which the formula numbers specified were absolutely unknown to us. We furnished the Graphic Arts standard, and the customer said, "That is exactly what I want;" so I am sure that any institution and practically every printing concern in the United States of any moment will and can furnish Graphic Arts standards. If they have their own number, then they have adopted these standards as regular and correct and are prepared to furnish them to anyone who requests them.

Alexander Murray.[7] In regard to the artist's connection with standardized colors or the colors used in printing, it is possible, as the author has suggested, for the artist to paint with practically the same colors as the engraver uses; and in that case it simplifies the engraver's problem and it eliminates a good deal of extra work, but at the same time it limits the possibilities for the artist. It is largely in the hands of the advertiser as to what he wants to do. If the advertiser selects an original which has been painted without any artistic restriction, without any color restriction, he may or may not get a satisfactory reproduction. It depends upon what means the artist uses to suggest his effects. If his effects were obtained by various deep layers of color—transparent pigment, for instance—that cannot be duplicated by any printing process, because we print with a very thin layer of color, and the psychological effect of a very deep, transparent pigment cannot be so duplicated. In one case the engraver may be able to retain the spirit of an original, without facsimile reproduction, but in another case, only a perfect reproduction may retain enough of the spirit of it to make it worth while using the original. This question is connected with the ability of the advertising man to size up what there is in the picture and what the engraver can get out of it. It seems to me that if any attempt is made to limit artists to the use of a few standard colors it would make it very unlikely that there would be any rapid improvement in reproduction methods. Very largely, the amount of improvement and the progress that has taken place in the methods of photographic reproduction are due to the difficulty of reproducing works of art and the fact that these works of art are "over the heads" of the engravers. There is something to aim at which they would not have if the artist "painted down" to their process.

Mr. Newton. We must not forget that people endeavor to get a facsimile, but it is absolutely impossible to get a facsimile of a water color, an oil painting, or a pastel drawing. Customers overlook this. Any water color or oil painting or pastel is no facsimile of a landscape; it is merely a representation, a sort of suggestion of what the painter saw; it is merely an imitation. The first thing a customer asks for is a facsimile of what the artist gives you. Bear that in mind.

Now, the second thing is, as Mr. Murray just has stated, that it is impossible and would be fatal to tell the artist, a man of ideas, a man of temperament, a man of ideals, that he must paint a picture in just three colors and that he must paint it in just this way. My experience is that it is very difficult to reproduce a thing painted in just three pigments. I do not say that it is impossible. We have only three inks to use, and some combinations that an artist will use are outside the limits altogether. It is quite impossible to reproduce them unless you have a special printing in an ink of the exact shade. Now, some time ago they reproduced some of Turner's paintings which were rather close to the original; some of them had as many as 40 printings, and they got something like 40 colors; and it is impossible to get that by a mixture of only three colors. That, also, should be borne in mind. What we must attempt to do is to approximate as near as we can to the artist, and if you reduce the artist to using only three-color paintings, it will be very discouraging and unpleasant, and it would be a sort of step backward instead of a step forward. We should not try to restrict the artist—although we may ask him not to use impossible colors—but otherwise give as much freedom as we can. As Mr. Ode said, you get the originals from all over the world, but you cannot expect that you are going to get an exact facsimile of an oil painting; that is an impossibility.

Mr. Farrell. I believe that a great many artists, the ones that make paintings for the magazines, will gradually be educated along this line. My experience is that some of our work that is coming through is more popular with the general magazines, and I think that we will gradually improve in the type of work that is coming through. When I first went into the standardization work, we started to apply it in our own office, and we had to impress the engraver with the use of standard colors to keep in mind the reproducing of our piece of art right from the beginning. There was just one problem that we had in our office, and that was with the reproduction of a package. We could see that with the standard colors we were using we were not going to keep near the package, and of the magazines that we used every one had a different blue; so we experimented and we settled that, and we do not have any further trouble, except that we found it is different from a standard blue. In that we arrived at the color with a solid blue; I would say a middle tone of the black, using the standard colors, and it turned out our package all right. We had to impress upon our engraver that he must keep the standard colors in mind. I think every engraver must first bear that in mind. After a great deal of fussing around we have the same color package today that we had a year and a half ago, by using blue and adding red to it. There is no doubt about it that if you just reproduce a painting and work it in any way, you will not get as good results as if you keep the standard colors in mind and work it intelligently.

[6] Queen City Printing Ink Company, Rochester, N. Y.
[7] Eastman Kodak Company, Rochester, N. Y.

William C. Glass.[8] It seems to me that there are two distinct fields—one which may be called the commercial, and the other the artistic. A certain manufacturer of a nationally advertised product when he gave out an order specified that the inks should be purchased from a named manufacturer and must be in certain colors. It worked a hardship, because there is no question that this ink could have been matched by other ink manufacturers. The point was that the advertiser, the manufacturer of the product, wanted exactly the same product in San Francisco as was made in the East. In some cases he did not get it even under these specifications. There was a wide variation in packages purchased from different plants. However, there is a difference of opinion on the question.

It seems to me that the first of these two fields includes a large part of the commercial trade, which can be standardized and in which the artist can be held to a certain color chart. On the other side there is the question of reproducing oil paintings of old masters, the reproducing of art panels, etc., all of which is distinctly related to the artistic field. In this work standards certainly cannot be maintained if faithful reproductions are to be made.

Irving F. Niles.[9] Some time ago we had considerable difficulty in getting the proper color effect on a job moved from our Chicago plant to our New York plant. We shipped the ink and paper from a lot that had been used in Chicago to New York, but for some reason, we could not get the same color effect in New York that we could in Chicago, and finally we had to ship the whole job back to Chicago. We tried our best to get the same color effect, but we simply could not get the thing right; in fact, we had a man come from Chicago to New York, and even then we could not get it. No, we did not bring the presses.

Mr. Murray. I would like to ask those who are familiar with the selection of the three-color standard inks of the American Institute of Graphic Arts whether any work has been done on the establishment of specifications based on spectral measurements of these colors or whether the standards are selected from certain manufacturers by rule of thumb without any other specifications of a scientific nature being adopted. Has anything of that kind been projected for the future?

Mr. Newton. There has been considerable done by the Bureau of Standards, and that is the nearest that would come to that specification; of course, none of them does come to that specification, but it is something to shoot at. There is a great deal of work being done on it, and I think we have made a great step in advance in getting the printing ink manufacturer to agree to standardization of colors, and I think that none of them thinks they are perfect. If you get the publishers to print with you and if you get the engravers to work with them, I think it is a step forward. Now, I think we shall improve on that in time and get them to adopt fresh standards. At the present time we are a hundred times better off than we were a few years ago. We are not satisfied; we are a long way from being satisfied, but we are making a step forward. Everybody is much more comfortable than when they started in this standardization work.

L. Bashwiner.[10] I think that commercially a good many jobs now being done in six, seven, and eight colors can be reproduced in four. In order for the lithographers to be in line with some of the printers, they must reduce the amount of colors they use. Where they have control of their own artists, I think that standardization can be accomplished. They have more chance to compete with the other printers than they have had in the past. I fully advocate the idea that a subject be reproduced in the standard colors, three or four colors, that is now being done in six, seven, and eight colors.

Mr. Niles. Mr. Bashwiner is right; we have found subjects that are now being printed in three or four colors just as good as any we have ever seen, and other lithographers have said that it would take seven or eight colors for the same subjects that we have printed in four colors.

### Author's Closure

The practical inkmaker, as I have known him in the past, has been a man that has learned by his experience rather than by any scientific research. I am sure that today there is more of a tendency to keep in touch with the laboratory than ever before. One of the best ways to react upon the inkmakers is for the customer to get after him; he is usually responsive to what his customers want, especially so if they say they will get it from somebody else.

I would say that Mr. Glass has "hit the nail on the head." Have enough printings, in reproducing an oil painting, to get what you want, and try to confine your commercial artists to a commercial line of colors, if that can be done.

We have learned a lot since we came here. I have a very good idea now of the whole thing. When I started out, I knew very little about standardization, but I have learned quite a little.

[8] U. P. M.-Kidder Press Company, New York, N. Y. Mem. A.S.M.E.

[9] Supervisor, Plants and Equipment, American Colortype Company, New York, N. Y. Mem. A.S.M.E.

[10] Karle Lithographing Company, Rochester, N. Y.

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# The Spirit of the Creative Age

By ROBERT W. DISQUE,[1] ROCHESTER, N. Y.

LET us go back to the middle of the fifteenth century and see what the savants of that period were thinking about. There are certain historical records which deal with the conflict of those who held sacred the original or humanistic art, popularly known as the hand-lettering art, with those proteges of Gutenberg, who advocated the new-found printing art.

It may be said that Gutenberg gave to mankind the inspiration which has marched on triumphantly through time and increased with fervor and force, each generation having been a contributor to the arts and inventions for the glory and advancement of civilization. Aldus Manutius, historically known as Aldus, took up the task as Gutenberg's life ebbed away, but it was a thorny path which he traveled.

But Aldus was determined. His was a great vision. The severity of the opposition of powerful patrons of humanistic art did not dampen his ardor in behalf of Gutenberg's invention. Aldus was more than a protege; he was a promoter of a new idea which he clearly understood, and which he regarded as revolutionary, yet highly important, not only as part of the evolution of book making, but most valuable "to illuminate," as he said, "a dark and troublesome age with the greater dissemination of knowledge."

One of Aldus' most severe antagonists was the Duke of Urbino, whose magnificent collection of humanistic art of the middle of the fifteenth century can be seen today in the Laurenzian Library at Florence, Italy. The Duke had this to say: "In that library the books are all beautiful in a superlative degree and all written by pen. There is not a single one of them printed, for it would have been a shame to have one of that sort."

It was Aldus' extraordinary physical endurance against persecution and bodily attacks which saved the day for Gutenberg's invention and really raised the curtain for the dramatic entry of the mechanical genius.

More than a third of a century of intimacy with the printing industry has permitted me to enjoy one thrill after another and many of them provided by the energy of the engineer.

I have seen an old Cottrell press, turning out 600 papers an hour, replaced by the web press printing 700 a minute. The old stereotype foundry that required 12 minutes to make a plate long ago passed into oblivion, to be succeeded by equipment making four plates in 3 minutes. The attache of the composing room would be amazed if he returned to life and visited his old haunts, for he would be bewildered by the complete change of scene, speed, and action. What a marvelous contribution to this great drama by the engineers of our present generation!

As recently as 10 years ago one would have been declared a madman even to hint a straight-line or progressive production for a composing room. But the genius has an uncanny way of anticipating difficulties and establishing certain fundamental principles to accomplish marvelous mechanical feats. And in this city of Rochester there is a straight-line production newspaper plant, probably the first success of its kind, at least in this part of the country.

Wander around a newspaper composing room and see what the mechanical engineer has contributed to progress. A third of a century ago all type was set or composed by hand. A first-class compositor would set about one line, column width, of news type a minute.

[1] Production Manager, Gannett Newspapers, Inc.

Presented at the First National Meeting of the A.S.M.E. Printing Industries Division, Rochester, N. Y., November 8 and 9, 1928.

A man named Mergenthaler, with a restless, tireless nature, felt the urge for invention. Others too, were afflicted with the same urge and made valuable discoveries and contributions toward the perfection of a typesetting machine. Mergenthaler's theory, however, seemed to be the most practical. Its simplicity of performance revolutionized the composing room overnight. The first Mergenthaler machine, for example, produced single column news lines four times more rapidly than could be accomplished by the speediest hand compositor. Furthermore, each line was cast on a solid slug, which made it possible for the printer to handle composition with greater ease and rapidity.

These first inventions of Mergenthaler were limited to the use of one size and style of type. The matrices, or molds, of type contained only a single letter and were known as one-letter matrices. Soon after the successful production of the single-letter matrices it was discovered that two letters could be cut into the matrix, and with a slight mechanical improvement, the printer could produce either a roman letter or an italic letter on the same line or slug. Of course, both letters had to be of the same size in order to pass through the type mold for perfect production of the letter and the type line. Therefore, the first type-setting machines produced four times more than the human hand, but only one size of letter and a line of news column width.

While the fundamental principles of machine-type composition have been retained, the genius of the engineer has been active in redressing the mechanism so that the performance of a modern typesetting machine is so diversified that it seems almost human. From four lines a minute the machine's speed of production has been increased to six lines. While the first machines cast an agate line about one-fourteenth of an inch in size, today a line nearly nine times larger is successfully produced. In the beginning a machine was equipped with one-letter matrices of a single size. Today the modern machines all have two-letter matrices, but the engineer has created a flexibility of mechanism which makes it possible for a single machine to produce as many as twelve styles and sizes of type. If Gutenberg and Aldus could come back to civilization today, what a glorious tribute the mechanical engineer of our time and generation could be accorded by those men who may be properly called the fathers of typographic invention.

The Intertype machine, too, has made notable contributions to the perfection of machine composition. The Intertype and the Mergenthaler employ practically the same fundamental principles of composition, casting, and distribution. While each machine has its own useful features of production and construction, both are accepted as standard equipment for the composing room.

Notwithstanding the remarkable accomplishments revealed in the typesetting machine, there are other mechanical geniuses who have made valuable and astonishing contributions to type-casting in order to facilitate the requirements of the newspaper composing room and to fill the demands of display advertising. The Ludlow type-casting machine makes it possible to produce type slugs ranging in size from one-fifth of an inch up to two inches. The Monotype machine's performance in type-setting and type-casting is really another wonder of the age. This machine extends its usefulness beyond type-casting and includes the production of dashes, rules, borders, and spacing material with a speed and accuracy which only the printer and the engineer can properly appreciate. The Elrod material-casting ma-

chine, also, has demonstrated its real value and worth in the newspaper composing room.

Today the compositor devotes all his time to production. Every letter and line of news or advertising appears each day in a fresh, new dress. No type is used the second time.

Every movement centered in the composing room of today reflects the thought and skill of the engineer; every device is a tribute to his genius, so that without the contribution of the mechanical engineer it would be utterly impossible for the newspaper to accommodate the reader and the commercial demands of our day.

But the untiring effort of the engineer penetrates every unit of the newspaper's mechanical departments. His work is again seen in the stereotyping foundry. As the type pages leave the composing room, the stereotyper greets them with an admirable simplicity of action and with the full assurance that with his skill and his mechanical devices he will fashion the page into a perfect reproduction within a few minutes.

In earlier days it required about 12 minutes to make a plate reproduction of a type page. Today a plate can be delivered to the pressroom in 3 minutes, if necessary. The improvements in molding machines, metal furnaces, casting boxes, cooling and finishing machines, automatic plate drops, startle the mechanical mind of yesteryear. What was then known as the wet mat, which required considerable time to prepare, is now replaced by the high-speed dry mat, delivered from the manufacturer and ready for instant service. Molten metal, which heretofore was carried in ladles by two men to casting boxes, is now electrically and automatically pumped into the boxes with but a touch of the hand. Casting boxes which in earlier days delivered one plate in three minutes now send to the finishing machine four perfect plates in three minutes. The hazards to men and product of the stereotype department have been greatly eliminated, and the speed has been increased fourfold by the mobilization of thought and action of the engineer and the foundryman.

Without the performance of a press, the last chapter of the newspaper drama could not be written. The whole civilized world pays tribute every day by its purchases of newspapers to the American press manufacturer. It is my belief that no civilized country is without an American-made newspaper press, so that the mechanical genius of the American engineer is far flung beyond the borders of his native land. Nor would I be mistaken in saying that Benjamin Franklin introduced American newspaper methods abroad, for it is a well-known fact that this extraordinary and historic character mobilized his resources, and several times the resources of others, to give our wonderful nation a place in the sun with the aid of the printed word.

One minute, and sometimes less, after the last plate or page is received, the press starts humming, singing its song of service to civilization. Racing against time, traveling at tremendous speed, yet issuing its product with accuracy and precision, these modern newspaper presses exalt the efforts of those who have made possible this marathon performance.

In days gone by, one unit, or a single press, operated independently of the other presses. Today a "hook-up" of any number of units has been made possible by the coordinated efforts of the mechanical and electrical engineers. The synchronization of motors enables productive expediency. The hook-up of units gives the publisher almost anything he wants to perfect a public service. The single-roll feed method of yesterday has been replaced by the triple-roll reel system of today. One roll of newsprint is fed into the swift-revolving cylinders with astonishing smoothness and accuracy. Replacement of rolls heretofore required a complete stop of the press; today the modern reel system has a fresh roll of newsprint in perfect position, ready to slip into its place of service while the press is in slow-down operation.

As the papers slide out to automatic conveyors in an endless stream, one is captivated by the neatly printed and folded copies, all counted and all ready to assist the circulation department in its exciting race to please and serve an interested and anxious public mind.

Rochester has a newspaper plant with a productive capacity which is perhaps the greatest in the world. The figures available lead me to say that the composing room doing the composition for The Times-Union and The Democrat and Chronicle probably turns out as many pages of news and advertising in a day as are produced by the largest newspaper plants in the world. Only the most modern equipment would permit such an enormous volume of composition.

The newspaper has been generously attended to, but inventive genius has been tireless in its labors to aid in the perfection of the printing art and industry. The commercial printer and the lithographer, the offset and intaglio printer, have all honored themselves with such contributions to the printing art as would have charmed Gutenberg and Aldus and softened the heart of the irreconcilable Duke of Urbino.

Students of philosophy and philosophers revel in the wisdom of Aristotle, Aurelius, Socrates and other giants of the early intellectual period. What a rich heritage we possess! And what a well of wisdom we have to draw from to stimulate and restrengthen our initiative. But theirs was only an intellectual age.

It seems to me that we are not lacking in appreciation of our inherited wisdom of the savants of earlier centuries, for the world today is proof of our energy and progress and of our performance, action, and achievements. We are not only thinking about things, but we are doing things. We can only maintain "the spirit of the creative age" by continued thinking, performance, action, and achievement.

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# Modern Bronzing Problems and Methods

## Public Demand the Reason for Universal Use of Bronze for Decorative Purposes in Printing—The Vacuum Bronzer—Automatic Conveyors for Bronzing Machines—High-Speed Vacuum Bronzing Machines and Their Operation

By WILLIAM C. GLASS,[1] NEW YORK, N. Y.

BRONZING is one of the least popular and most important operations in certain branches of the printing and lithographic industries. It is often referred to as a necessary evil. Twenty years of personal experience in this field has, however, witnessed a phenomenal increase of the necessity and a reduction, amounting practically to elimination, of the evil.

Necessity for the bronzing operation is so obvious as to be overlooked, but this necessity is so thoroughly grounded in natural laws as to establish its permanency beyond any attempt or desire to modify or eliminate it. Gold and its visual substitutes hold a unique place in this world of ours for two reasons: first, gold is a precious metal, and second, it possesses color properties which are entirely lacking in any other vehicle used for decorative purposes.

From time immemorial man has intuitively considered gold as the standard of intrinsic value and the symbol of worth and merit. The Babylonians applied gold leaf to the mural decorations of their temples; the Egyptians used it in coating the mummy cases of their kings; the Greeks gilded the colossal statue of Athena which crowned the wondrous architecture of the Acropolis; the Romans used gold in the decoration of household furniture; the monks of the Middle Ages used it to illuminate their manuscripts; the old master painters used it to adorn the frescos of their cathedrals and abbeys; Louis XIV, "Le Grand Monarque," reveled in it, as did the art of the Near East from the Moors of Spain to the Moslems of Byzantium, and the countries of the Far East, India, China, and Japan.

Today gold is used everywhere for decorative purposes. A careful examination of any decorative or color scheme which makes a special appeal and commands unusual attention will invariably disclose gold as the element without which it would lose its individuality. And so through the ages the impelling lure of this wonderful metal has found its reflection in a demand for bronze as a decorative medium wherever the esthetic taste is relied upon to build up an appeal, whether that appeal is simply to satisfy the artistic temperament or to attract the prospective purchaser. This principle has successfully withstood the test of competitive endeavor.

In its chromatic value gold may be considered as both a neutral and a contrasting color. While it harmonizes with all colors it also serves to set them off and to enhance the value of every hue and tint. It is a perfect foil. Doubt that gold is a perfect foil for pictures in color will be at once dissipated by the inspection of any art gallery where the unanimity with which artists have adopted gilt or bronze for their frames will be at once apparent. As for the use of gold as an integral part of a decorative painting, we have only to point for authority to such master American painters as Sargent, Abbey, and Maxfield Parrish. Some years ago a small group of rebellious artists started a movement to supplant the traditional gold frame with frames of black or dark-finished wood. For paintings in color it was a failure. The public, which is always the ultimate judge, could not be won over; they recognized the appropriateness and the artistic color relation of gold.

### Public Demand the Reason for Universal Use of Bronze for Decorative Purposes

For the same reason it is public demand which has increased the use of bronze by many tons, until today even a guess at the total volume used would be hazardous. The successful use of bronze means the unhampered salesman, the emancipated artist, and the satisfied customer. Public demand is the one big reason for the universal use of bronze on practically every commodity which is offered for sale in package form. If there is any disposition toward skepticism, one has only to survey his own home and he will find bronze labels in use from the kitchen pantry through every room in the house. Bronze labels are used on canned goods, packages of foodstuffs of every description, bottle labels, cosmetic boxes, phonograph-record labels, playing cards, cigarette packages, cigar bands and boxes, hosiery and all kinds of textile labels, writing paper, decalcomania transfers, candy-box wrappers, chewing-gum wrappers, souvenir postal cards, and so on through the entire line wherever a label or wrapper is used on any type of merchandise or wherever a decorative scheme is relied upon to stimulate sales appeal.

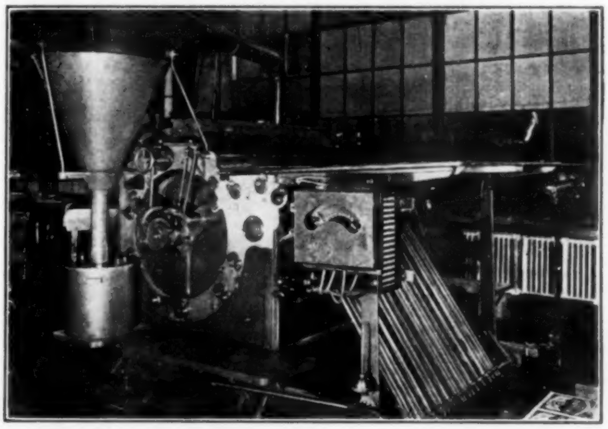

Fig. 1 Standard Fly-Delivery Vacuum Bronzer Arranged for Hand Feeding

(Note that the cyclone exhausts into the pressroom with no outdoor connection.)

This lengthy preface is not to be construed as an excuse for bronzing, but rather as a reason for its being and as a warning to those who may feel that it is not of sufficient importance to merit serious consideration from the standpoint of necessity for equipping with as up-to-date and efficient machines for this operation as for their other manufacturing processes.

The antipathy of the printers and lithographers toward the bronzing process is not without foundation, because the mere mention of bronze doubtless carries many of them back in retro-

[1] Mem. A.S.M.E., Past-Chairman of Printing Industries Division.

Presented at the First National Meeting of the A.S.M.E. Printing Industries Division, Rochester, N. Y., November 8 and 9, 1928.

spect to their apprenticeship days when bronzing was done by hand. This meant rubbing bronze on a printed sheet with a wad of cotton batting, and then brushing the sheet again with another wad of cotton batting to remove the surplus bronze. In those days bronzing had to be done in an isolated part of the plant, because the powder spread rapidly through the room and covered every-

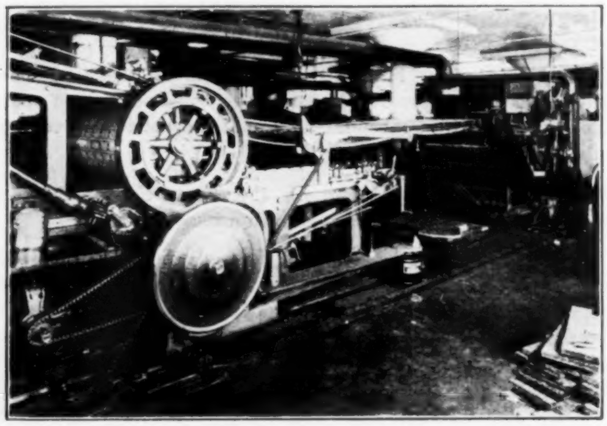

Fig. 2 Standard Fly-Delivery Vacuum Bronzer Connected to a Two-Revolution Flat-Bed Printing Press by Means of an Automatic Drive and Conveyor Mechanism

(Guards have been removed from conveyor brackets to show sprocket and chain drive. Note that cyclone exhaust is connected out of doors.)

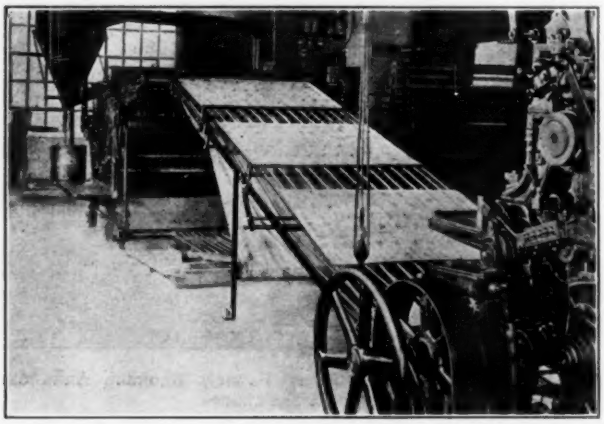

Fig. 3 Standard Fly-Delivery Vacuum Bronzer Connected to an Offset Press of the Positive—or Floor—Delivery Type by Means of an Automatic Drive and Conveyor Mechanism

(This outfit is limited in speed by the bronzer to 1800 per hour, even though the press will run 3000. Note pulley blocks for raising conveyor from press when bronzer is not in use.)

thing in its path. The boys who did the work usually wore sponges over their noses to prevent inhaling too much of the bronze dust, and they were also supplied with a plentiful quantity of milk to drink as an antidote for the supposed injurious effects of the bronze dust. One can hardly be blamed for wanting to avoid such a condition. In spite of this condition, however, the demand for gold increased, and as a natural consequence machines were developed to take the place of this hand operation. The machines were a decided improvement, of course, but were far from satisfactory because they cured only some of the evils. It was not until 1907 that the first so-called "vacuum" bronzer with a positive delivery was introduced to the market. This machine met with instant and universal approval, and was adopted by the leading plants throughout the country.

## The Vacuum Bronzer

This vacuum bronzer consisted of two cylinders, each provided with grippers. (Fig. 1.) The sheet, which had been previously sized in a printing press, was brought to the bronzer and fed to gages similar to the press itself. The grippers in the larger cylinder engaged the sheet and carried it around past successive pads and rollers, then transferred it to grippers in the second cylinder, with the face of the sheet against this cylinder so that the back of the sheet could be dusted. The sheet was then delivered to a fly mechanism, similar to the well-known fly delivery on a printing press.

There is no intention in this paper to discuss differences in particular mechanisms between various types of bronzing machines, but rather to point out certain fundamental principles which in themselves have dictated ultimate results. It is a fact, however, that no fundamental change has been made in the principle of the vacuum bronzing machine in the last twenty-one years. The changes which have been made in vacuum bronzers have been dictated more by changing conditions in industry than by a necessity for improvement in the machine itself.

Attempts have been made to revert somewhat to the so-called flat bronzer which was discarded by the lithograph trade many years ago as inefficient, inadequate, and generally unsatisfactory. In this type of machine, generally speaking, the sheet is carried through on a belt or tape in a straight line instead of going around a cylinder. Practically all flat bronzing machines have no grippers to carry the sheet through, but depend entirely on friction. Such machines operate with fair results on heavy paper and cardboard, but when the paper is at all curly or uneven the leading edge is usually crumpled or torn, resulting in a total loss of the sheet. It is also a demonstrated fact that in this type of bronzer the sheet cannot be properly burnished and dusted. Experiments with bronzing machines of the flat type equipped with grippers have been equally unsuccessful. Bronzing machines of the flat type are comparatively inexpensive to build; they have been known to the trade for many years, and yet there are so few in use, except in very small sizes, as to practically eliminate them

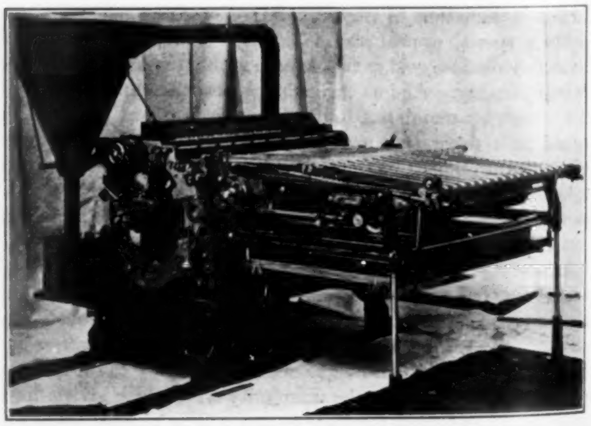

Fig. 4 Standard High-Speed Vacuum Bronzer of the Two-Cylinder Type, With Lowering-Pile Delivery

from serious consideration. They cannot be considered as at all efficient for mass production. They are short-run or special-purpose machines. On the other hand, when 80 to 90 per cent of all the bronze work in this country is being produced on a certain type of cylinder bronzer, that in itself is conclusive proof of its efficiency and constitutes a vindication of the underlying principles on which it is built.

### Automatic Conveyor for Bronzing Machines

When the vacuum bronzer was first introduced to the market, automatic feeders and high speed were not the watchwords as they are at the present time. Developments along these lines, however, soon led to the automatic conveyor for bronzing machines about the year 1911. (See Fig. 2.) This is a simple tape device which connects the delivery mechanism of the press with the bronzer so that the sheet can be fed directly and automatically from the press, after being sized, to the grippers of the bronzer and thence carried through the bronzing operation for delivery to the jogger board of the bronzer. When using a conveyor the bronzer is driven from the press-driving motor by means of a roller-chain connection so that both machines are synchronized. The conveyor can be readily disconnected when the bronzer is not required, so that the press may be used for other work independently of the bronzer.

The conveyor made possible service and improvements which could not have been anticipated before its introduction. The practice in hand feeding was to carry several sheets from the press over to the feed board of the bronzer and then feed them through the bronzer by hand. Obviously the last sheet out of the press would be the first sheet into the bronzer, and the first sheet out of the press would be the last into the bronzer. There would be a noticeable difference in the quality of work between these extremes, making it necessary to carry a sufficient body of size on the sheets so that the last one into the bronzer would still take bronze.

This hand feeding also required considerably more labor and resulted in a great amount of spoilage, besides the loss of time and decreased production.

With the automatic conveyor, the sheets go into the bronzer at a predetermined time after being printed with size, so it is possible to reduce the amount of size to the minimum and still obtain a satisfactory bronzed job. There is no loss in production, because the bronzer is timed absolutely with the press; there is no excess of labor, because the bronzer is fed automatically from the press.

With the rapid increase in popularity of the offset press new problems arose in bronzing requirements, and these problems were not confined entirely to the necessity for increased speed. With printing presses, the usual practice was to confine the bronze work to one press and have the bronzer connected to this press with a conveyor. There were many differences of opinion

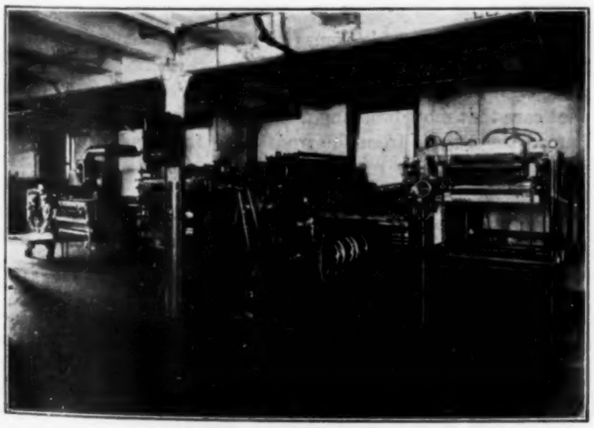

Fig. 5 Standard High-Speed Vacuum Bronzer Connected to an Offset Press by Means of an Automatic Drive and Conveyor Mechanism

(The sheet is not touched by hand after being put into the automatic feeder of press until it is removed from the pile delivery of the bronzer, speed, 3000 sheets per hour.)

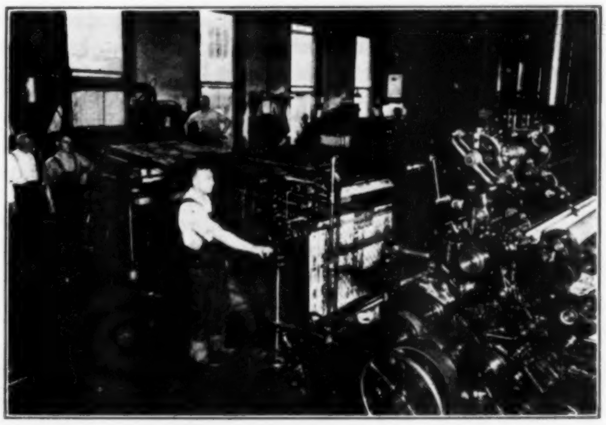

Fig. 6 Standard High-Speed Vacuum Bronzer Connected to an Offset Press, Showing Course of Sheet From Delivery Mechanism of Press to Feeding-in Tapes on Bronzer

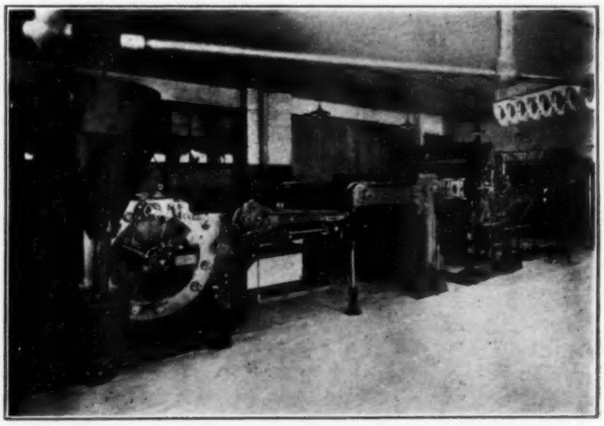

Fig. 7 Standard High-Speed Vacuum Bronzer Connected to an Offset Press

(This is a special installation because of limited space available in which to install the bronzer. The bronzer is mounted on special wheels and tracks set into the floor. As shown, the bronzer is rolled up to the press delivery into operating position, leaving a passageway behind the bronzer. When not in use it is rolled back against the wall, leaving a passageway between the press and bronzer.)

Fig. 8 Standard High-Speed Vacuum Bronzer Connected to a Direct Rotary Press

(This is a special installation. The press is used for bronze work exclusively and the machines are arranged with the delivery mechanism of the press directly above the feeding-in tapes of the bronzer. Neither the press nor the bronzer can be used independently of each other. Speed 2500 per hour.)

on this same question in regard to offset presses, because it was felt that all the colors, including bronze sizing, had to be printed on the same offset press in order to assure accurate register. It seems, however, that this objection has been fairly met, because the benefits of printing colors on several presses, and especially in large plants, have been so great as to merit careful attention. The bronzing operation was benefited thereby, so that at the present time, except under unusual conditions, a bronzer can be connected up to one offset press in a group and all of the bronze work can be diverted to this one outfit, regardless of the offset press or presses on which the preceding colors were printed.

### High-Speed Vacuum Bronzing Machines

The problem which the bronzer manufacturer had to solve was that of increased speed, and this has been accomplished by high-speed vacuum bronzing machines which are capable of maintaining guaranteed speeds of 3000 sheets per hour.

These high-speed machines are the same in principle and in all essential mechanisms as the original vacuum fly-delivery bronzer, except that the fly-delivery mechanism has been replaced by a lowering-pile-delivery mechanism. (Fig. 4.) In some cases the bronzing cylinder has been provided with two sets of grippers diametrically opposed so that two sheets can be bronzed for each revolution instead of one as in the case of the fly-delivery machine. (Fig. 5.) This feature permits of 3000 sheets per hour with the bronzer actually running only 1500 per hour, which was the average speed for hand feeding.

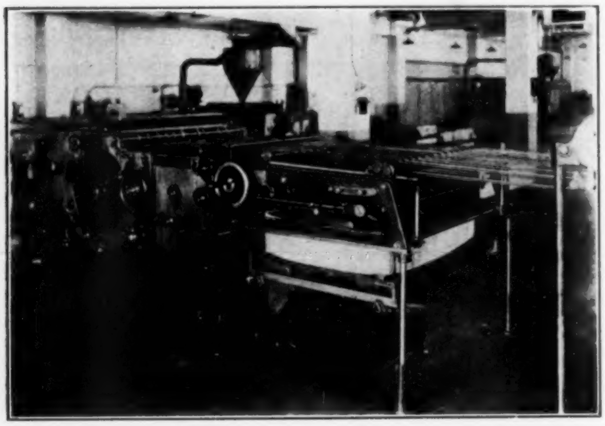

Fig. 9 Four-Cylinder High-Speed Vacuum Bronzer Connected to an Offset Press by Means of an Automatic Drive and Conveyor Mechanism

(This is the latest development in high-speed bronzing, producing absolutely clean sheets at the rate of 3000 per hour.)

The all-important objective is, of course, the cleanest possible sheet. Before the introduction of the vacuum bronzer there were dusting machines on the market through which bronzed sheets were fed for an additional dusting. The introduction of the vacuum bronzer solved this problem of bronzing and dusting in one operation in a highly satisfactory manner, except for certain unusual requirements. There are some classes of work which have to be dusted again because of subsequent operations. This dusting, however, is not necessarily due to the failure of the bronzer to dust the sheet properly. Bronzing consists of impinging a coating of bronze flakes on a somewhat tacky surface of sizing. When this surface under the bronze dries it will be found that there are many unattached flakes of bronze lying free or between other attached flakes on this surface. Running the hand over the sheet dislodges these flakes or breaks off the tops of others which may be simply held by a point in the sizing.

Therefore, for such bronze work as had to be subsequently calendered or varnished, it was found advisable, if not always necessary, to dust the sheets again. For this operation also the old-fashioned dusting machine gradually gave way to the bronzer because the latter could be readily cleaned out and the sheets put through a second time for an additional burnishing and dusting. Many concerns equipped themselves with an additional bronzer to be used exclusively as a duster. Then in case of an emergency the duster could also be used as a bronzer. The most efficient dusting machine consists of a bronzer with an automatic feeder attached to eliminate the hand feeding operation. It is advisable to allow bronzed sheets to stand for several hours between the bronzing and dusting operations. On the other hand, good results can be obtained by running the sheets through the bronzer immediately after being bronzed, provided the bronzing has been done on a machine equipped with an automatic conveyor so that the minimum amount of sizing has been used.

Combining these thoughts produced the obvious result of a still further improvement in the vacuum bronzer in a four-cylinder machine which has recently been introduced to the trade. (Fig. 9.) This machine is practically two machines combined in one. It has two distinct vacuum attachments, one for the bronzing unit proper and one for the dusting unit. The sheets can be taken from this new bronzer and run through a varnishing machine without redusting which is the most severe test that can be applied. It represents the ultimate of perfection in bronzing equipment, because it combines speed with quality and an absolutely clean sheet in one operation. It would be far-fetched to say that the two-cylinder bronzer has outlived its usefulness, but it is not exaggeration to say that the four-cylinder combination bronzing and dusting machine is the ultimate answer to the bronzing question.

As has been suggested, bronzing is somewhat of an unpopular operation, and has therefore suffered greatly by lack of attention from executives who have been satisfied to leave this part of the work to more or less indifferent supervision. This is an expensive policy, however, because bronzing is usually a finishing operation after an expensive sheet of paper has been made more valuable by the addition of many printings of color and the expenditure of much labor. A sheet wasted in the bronzing operation represents considerably more in expense than one wasted at the press, and yet in many cases the bronzing operation is indifferently supervised and left to unskilled and uninterested operatives.

### Points to Be Observed in Operating Bronzing Machines

There is no reasonable excuse for bronzing to be unpopular. If a printing press, paper cutter, folding machine, or any other piece of mechanical equipment had the inadequate and unintelligent care that most bronzing machines receive there would be an immediate crusade from the front office to fix the responsibility and discipline those responsible for the condition. A bronzer can be kept clean, and the bronzing operation can be made no more obnoxious than any other in the trade. Obviously, if the amount of bronze fed into the machine could be confined to exactly the quantity required for the sheet being bronzed, then there would be no surplus to require an extra brushing, and there would be no surplus to dirty the machine and escape into the pressroom. Various mechanisms and adjustments have been provided so that the quantity of bronze can be regulated toward a minimum according to the particular job being run. The difficulty is that most operatives never pay any attention to feed except to see that there is enough, working on the basis that the surplus is reclaimed by the vacuum system. Most of it is reclaimed under normal conditions, but the vacuum system is designed to meet certain conditions, and when overtaxed it simply will not take care of the excess, which is then free to escape into

the pressroom or lodge in the recesses of the machine itself.

Another important point in connection with the bronze feed is that the job should be started with too little bronze, because this will then show up low spots in the make-ready on the press. It is better to bring up a few spots here and there on the press than to flood the sheet with bronze to make up for them.

The question of separate rooms or compartments for the bronzing operation is also deserving of comment. The author is opposed in principle to segregating the bronzer. It is at once an admission of the belief that the bronzing operation cannot be clean, and produces the wrong psychological effect on those responsible for this operation. The great majority of vacuum bronzers are being operated in the open pressroom near other machines and paper stock, with no likelihood of damage to either except through carelessness.

The question of connecting the cyclone of the vacuum system with the outer air is one which can best be met in the individual installation. Where it can be connected out of doors it is best to do so because a considerable volume of air issues from the top of the cyclone, and if this exhausts into the pressroom it will set up a current of air through the pressroom and this current will carry with it not only the loose bronze which may be around the machine but any other dust which may accumulate. With the proper outdoor connection no bronze will escape from the machine, but on the contrary it will be returned to the receptacle supplied for this purpose. With an outdoor connection improperly installed there is every likelihood of a back pressure, which will result not only in bronze issuing from the outlet out of doors but also through the fountain door and other openings in the machine itself.

The use of pure aluminum bronze should be carefully supervised, because pure aluminum is highly inflammable and is susceptible to flash fires and possible explosions. The motors operating in close proximity to bronzing machines should be of the fully enclosed type or provided with enclosing covers, especially when on direct current. All electric wiring about the bronzer should be carefully done to insure against short-circuits and the possibility of flash fires. This refers, of course, only to aluminum bronze, because gold bronze is not inflammable.

It is many times found necessary to powder sheets with magnesia, especially in a lithograph plant, if it is desired to run gold or subsequent colors without allowing the necessary interval of time for natural drying. This is usually done on a bronzing machine. This practice should be discouraged, however, as much as possible, because magnesia ruins rolls and pads very rapidly. If the operation must be performed, then it is advisable to have a special bronzer set aside for this purpose. If this plan is not practicable, then there should be an extra set of rollers and pads kept for powdering only.

### Best Results Obtained With High-Grade Bronze

The subject of bronzing machines would be incompletely covered without some reference to bronze itself. There are many qualities and grades of bronze: some are fine, almost a powder, while others are coarse and more or less sandy. Some bronzes are dry, others are greasy. Some bronzes are heavy and solid, while others are light and fluffy. There is no single rule which applies except the rule of common sense according to requirements. In general it is safe to say that the bronze which is cheapest in price is usually the most expensive when it comes to the cost sheet. In case of unsatisfactory results with bronze, the wisest policy is to solicit the advice and counsel of the bronze manufacturer. No particular quality or grade of bronze will produce equally good results on all kinds of paper any more than will the same kind of ink produce satisfactory results on all kinds of paper. The requirements should be studied intelligently. The same sort of reasoning applies with equal force to the sizing. There is no universal sizing which will answer for all kinds of paper and all kinds of bronze. Many printers have thought they could mix up all their old ink and use it for sizing because it is hidden under a coating of gold, but they were never further from being right. It pays to give careful attention to the sizing and thus avoid unsatisfactory, and in many cases disastrous, results in the finished job.

It pays to buy a consistently high-grade bronze, because it has greater covering capacity per pound than cheaper and lighter bronze. When mixed with new bronze it can be used over and over without impairing its luster beyond the usable point, and

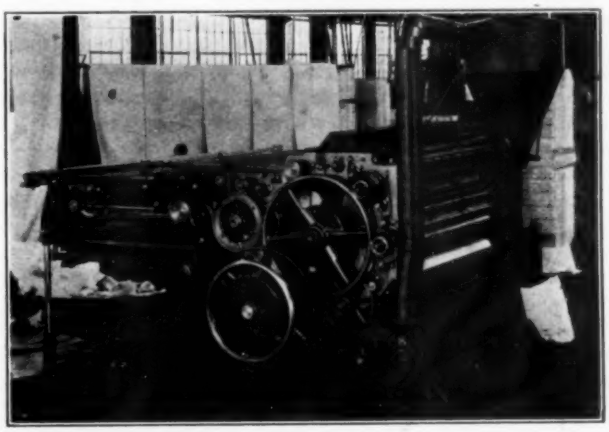

Fig. 10 Rear Doors and Guards Removed From Standard High-Speed Bronzer, Showing Particularly the Reciprocating Bronzing Pads and Cams for Operating Them

(This mechanism is the same also on the fly-delivery and four-cylinder high-speed bronzer.)

still give practically as satisfactory results as the use of entirely new bronze. As a matter of fact, it is preferable to mix a small quantity of used bronze with new bronze because it gives practically as good results as to quality and makes it much easier for dusting. This, however, should be thoroughly and carefully done outside of the machine, and the bronze put into the fountain in a mixed state. The use of the bronze-receptacle vacuum system is strongly urged because this brings the unused bronze into the receptacle where it can be sifted, weighed, and worked in with new bronze before being used again in the machine.

Too much attention cannot be given to these apparently minor details, because the sum total of these details usually spells the difference between quality and efficiency on the one hand, and poor work and inefficiency on the other.

Bronzing is here to stay, and is increasing rapidly from year to year. It might be well in closing, therefore, to repeat and to again state definitely that this operation is of sufficient importance to merit the most serious consideration and investigation from the standpoint of equipment and supervision.

## Discussion

H. A. Bernhardt.[2] I do not agree with the author when he claims that the average lithographic plant manager is very careless when bronzing a job. It is my experience that the man in charge of the bronzing is really more careful with the bronzing of a job than with any one of the other colors of the same job. Bronze is usually the last printing, and therefore any spoilage at this stage is relatively more costly. Also the bronze is very often

[2] Manager, Latham Lithograph Company, Long Island City, N. Y.

a greater single factor than any other single color, and therefore would normally command greater attention in its application.

Regarding the wisdom of using bronze, recently a customer (who is among the largest advertisers in this country) was in a great hurry to get out a folder which was to be embellished with a bronze border. He suggested that we omit the bronze border, hoping thereby to gain several days in the delivery time. We therefore submitted a proof, substituting a gray border for the bronze one, which gave a very displeasing effect and therefore was not approved by the customer, who then cheerfully granted the necessary time to apply bronze, as originally planned in the design. The job in question was a fine Christmas greeting in eight colors and bronze. By omitting the bronze it would have suffered in artistic beauty.

I agree with the author that bronze, if applied with artistic judgment in the original design, is very much desired today, and with the modern bronzing machinery and improved methods, bronzing presents an added profit-producing operation that is too often overlooked by the average lithographer.

Randolph T. Ode.[3] What does the author think of printing on top of bronze or bronze ink?

Mr. Glass. That is an open question. Only in instances where plates are made in the old way is the bronzing usually done first, because the gloss is lost as a rule in going through the presses several times. It is preferable to put the bronze on last as a finishing operation.

A great deal of attention is being given to the matter of printing a varnish size over the bronze, which keeps it from coming off. I think it is open to some discussion, but it is certainly all right with some classes of work.

Mr. Bernhardt. As to applying bronze and then printing or lithographing over it, we have done it on several occasions. We have an especially beautiful effect in the picture of a bronze Indian where we have done the bronze in the first printing and then have added the various colors to the picture of the Indian, and we have obtained a very beautiful effect which could not have been secured had we put the bronze on in the last operation, because the portions that did not receive any ink were the lustrous eyelashes that were absolutely a gold effect, and the picture resembled a bronze statue. All of this requires foresight, because that bronze has to be thoroughly dried, for a week at least, and in applying those printings we double-printed one or two of those colors in order to get the effect, but the result was something worth while. Whether that can be practiced commercially I do not know. I have seen some sample labels with one color put over solid bronze.

R. F. Reed.[4] There is a matter that seems to be vague in the minds of some of the lithographers. Some of them print the gold size on the sheet from electrotypes, others from stone or from metal, by direct lithography, while still others use the offset process. Of course, if you use the offset press, you secure a thinner film of size on the sheet than by the other methods. It is a question as to whether bronzing can be done as satisfactorily by printing the size on the offset press as by the other methods. I would like to ask whether in the opinion of the author it can be done more satisfactorily on the offset press than by means of electrotypes? With reference to the matter of explosions in the use of aluminum bronze, I know that explosions have taken place in bronzing machines. Has it ever been proved that static electricity would cause such an explosion? Of course, in dry weather there is considerable static electricity generated in the bronzing machine.

Mr. Glass. Answering the first question, I would say that there is no doubt that the body of size from the offset press is less than from the electrotype plate, and care has to be taken so that the colors underneath do not show through. I say frankly that, given the opportunity to do it, I lean very much to bronzing from electrotype plates with a high-speed rotary press, whether the previous colors have been put on by offset or by stone or electrotype or any other process. The answer to that depends very largely upon what the various lithographers and printers are doing. I have been called in by requests for information as to what was wrong with the bronzing machine because the customer was not getting the proper covering of gold from the offset presses, whereas the real difficulty was in the offset press itself in not giving the proper amount of sizing. It is sometimes necessary on the offset press to print a color and then print the gold size over that. The extra color can be avoided many times in making plates for the other colors. The way to get the most satisfactory job is to print the bronze from the electrotype plates.

With reference to the second question about explosions, I know of only two instances where there have been explosions, and in neither of these cases were experts able to determine exactly what caused the explosion. It might have been static. I rather doubt it. I do not think it would be possible to build up a sufficient amount of static going through a bronzing machine to explode aluminum dust because if that were true we would have had many more explosions than we have had. Enough static is generated many times to make it difficult to deliver the sheet, for the reason that in a bronzing machine the sheet is held against a metal cylinder and is burnished by pads and rolls. It seems to me that if static had been the cause generally, there would have been many more static explosions. Two have occurred within the last ten years; the percentage is very small. It is my opinion that static has not caused the explosions. I think it was caused by a short circuit in one case and perhaps by a spark in the motor in the other case.

W. T. Edgell.[5] Is the explosion due to the static or to a spark in the commutator?

Mr. Glass. One of the ordinary tests for pure aluminum powder is to take a sheet of paper with aluminum powder sprinkled on it and to tap it so that the powder will go up in the air as a cloud, and then touch a match to it. If it burns freely, you will know that you have pure aluminum; what is left is lead. It proves to a certain extent also that some proportion of air is necessary. A spark from static is a momentary discharge that cannot be easily measured. It is doubtful if it could cause such an explosion except under certain conditions.

Walter E. Sooy.[6] I would like to ask a question of the author with reference to printing. The job may have several colors printed on a sheet, for example; it may be printed on a single-color press. The sheet is dried between each color; it shines where these colors lap. Is there anything in the bronzer or dusting machine to eliminate the bronze clinging to that portion of the sheet that shines or has a glossy finish due to the overlapping of the colors, or do you consider that a material or a production problem?

Mr. Glass. Having got into the difficulty, there are two half-

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[4] Director, Department of Lithographic Research, University of Cincinnati, Cincinnati, Ohio.

[5] General Electric Company, Schenectady, N. Y.

[6] Secretary and Plant Manager, Michigan Carton Company, Battle Creek, Mich. Mem. A.S.M.E.

ways out. The first one is to magnesia the sheets; the second is to dope the bronze. Now, there is a question that has not been touched—the question of doping the bronze. There have been many ideas for doping bronze. Aluminum hydrate seems to be about as satisfactory as any and appears to have the effect of acting as a magnesia operation as well. Many times it acts as a vehicle for carrying the bronze as well as powdering the sheets. I am frank in saying that that is a manufacturing problem before you get to the bronzing operation.

Doping the bronze has to be done very carefully so far as proportions are concerned, because if too much is used it will dull the luster. There is a point which you can approach which will not affect the luster appreciably.

George C. Van Vechten.[7] I think that it is possible to develop an installation of a bronzing equipment that is not what would be called dirty. The conventional method is to use a centrifugal-type separator in conjunction with a fan, creating a vacuum in the machine. This system produces a pressure type of separation so that the bronze will fly or be distributed in the room from every aperture or crack. At present we have an installation of twelve machines in which we connected the air discharge from the centrifugal separators to a vacuum line, and then we developed an additional separator, which was also under vacuum, and thus we collect the bronze which the first separator does not remove; this is a second operation. In addition to that, in order to capitalize the air, which is being wasted, for refrigeration purposes, we had to have a rotary viscous air filter. With that it is possible to discharge the air back into the room perfectly clean. By utilizing the vacuum system we have very little bronze in the room. I think probably that would be the solution of the problem for future installations.

### Author's Closure

In thinking over the presentation of my paper, I wondered how much discussion could be started on the question of "bronzing." The reason for this statement is that there seems to be such an antipathy to the process of bronzing that it is difficult to get anyone to think seriously about it until he is faced with the necessity of bronzing, and only then does he become partially interested in the subject. It is sort of an "orphan" process and has not been given the necessary attention.

Bronzing is one of the least popular and most important operations in certain branches of the printing and lithographic industries. It is not popular, principally because many executives look upon it as a dirty operation that has to be endured. It is important, however, because we all know that gold is the one thing that adds value and beauty to anything, whatever it might be, and it is a strange thing that gold, which is the one color that acts as a foil, is the only color that will harmonize with any other color, and it also represents intrinsic value. This attracts the eye and ultimately attracts the sale, and that is what we are all aiming at.

Gold ink cannot be made to give the same color value and luster as bronze. Gold ink is composed of varnish and gold bronze mixed together, and therefore produces a surface of gold and varnish in which the luster is immediately destroyed. Gold bronze consists of a bronze powder dusted over a varnish and accordingly gives the full luster and quality of gold bronze.

A good many people seem to think that working on a bronzing machine is a killing operation. It is no more killing or dangerous than any other operation on any industrial machine; it is no more dangerous than any other dust you might mention or might sweep up on the workroom floor.

[7] Superintendent, Stecher Lithograph Company, Rochester, N. Y. Assoc-Mem. A.S.M.E.

The old way with the vacuum bronzer was to hand-feed it, but hand-feeding is now out of date and inefficient, and is accompanied by spoilage and waste, and the work also is not so good. For instance, you take fifteen or twenty sheets from the printing press over to the bronzing machine. Obviously the first sheet off the press is the last sheet into the bronzer and vice versa. You can take those twenty sheets and spread them out and see a difference in quality from one to the other. Aside from the question of waste and spoilage from the handling of the sheets through this operation, there is enormous waste of bronze and even of time. There is a considerable percentage of bronze which goes through the machine and which does not touch the paper at all.

Eighteen years ago the question of feeding bronzing machines automatically was taken up, and a mechanism was developed for feeding the sheets automatically from the press into the bronzer. That helped a very great deal. I talk conveyors because I realize that they help the printer and help the bronzer. Sometimes too much emphasis was put on the first cost of the conveyor. The average man saw the price of the conveyor without the returns he would get from it. Then there was the question of connecting up the bronzer with the conveyor to a certain press of a group. Some argued, and still do, that it is impracticable and sometimes impossible to run all the colors on one press and the bronze sizing on another press. I think it is only in the exceptional case that the lithographer actually has to run all his colors and the bronze on one press. I understand certain makers of offset presses go so far as to guarantee register from one press to another. If we do not face these questions squarely we will go on in the same old rut. However, with the rapid increase of popularity of the offset press new problems are ever occurring, not confined entirely to the necessity for increased speed.

Now comes the question of high-speed bronzing. The question of increased speed is one that is open to a great deal of discussion. What do we mean by high speed? There are no rules to cover speeds of offset presses. Speed depends on the job, depends on the paper, on the ink, on the amount of ink on the paper, and on many other variables.

What is the maximum speed required of a bronzer from the viewpoint of the lithographer or the printer? It seems to be the unanimous opinion that 3000 an hour would be ample. Some offset printers guarantee 4500 on certain classes of work. Well, if you can size a sheet at 4500, we will give you a bronzer that will bronze at that speed, but I think we ought to come down to brass tacks. I say frankly that I am not a lithographer or a printer, but I have yet to see a bronze job that can be run at 4500 an hour on large size sheets.

High-speed bronzing, of course, means automatic feeding from the press to the bronzer. That is being done today in many plants in this country, as high as 3600 an hour, but 3600 an hour is not an average speed; 2800 is an average speed; a guaranteed speed under most conditions is 3000. I have seen them go anywhere from 3000 to 3600; 3600 on a very good sheet, straight edge, heavy stock, very little bronze on the sheet. The all-important thing in bronzing machines is the clean sheet, and therefore we come to the question that is the most difficult of all to answer, what is a clean sheet? A clean sheet on a certain kind of wrapper or label will not answer at all on certain other kinds of wrappers or certain other kinds of labels. We run into that question continually, so we must arrive at some basis on which to judge the average. A cigarette-package wrapper presents a fairly good example of a commercial bronze job. At the same time it is not comparable to some of the high-grade candy wrappers, which are printed in many colors. It is rather difficult to answer when asked whether we are able to guarantee that the bronzer will give an absolutely clean sheet. When I truthfully say "No, we do not guarantee an absolutely clean sheet," the prospect

immediately loses interest, feeling that he wants an absolutely clean sheet. Then if I show him a commercially clean sheet and say, "That is what we guarantee," I find him rather surprised at the quality of the work. So you see, that is an unsatisfactory procedure.

Now, up to this time, in order to get commercially clean sheets, it has been necessary to run the sheets through a dusting operation after the bronzing. Of course, that means an extra operation and thereby another chance for increased waste, inefficiency, and increased cost. Some of our larger lithographers and printers have taken their old bronzing machines and put automatic feeders on them, thereby increasing their production on the dusting; however, that is not entirely satisfactory. Some have even installed high-speed bronzing machines with a feeder in order to get the speed desired. Something had to be done about it, and the result has been a further development in the high-speed bronzing line, with the dusting unit built into the bronzing machine. In other words, instead of taking the sheet from the bronzer and then over to the dusting machine the sheet goes into the bronzer, then into the dusting unit and then into the delivery. That raises a question as to whether that gives a clean sheet. If you take a pile of sheets from a bronzing machine and let them stay over night or two or three days and then dust them, you will get a cleaner job than by dusting them immediately after they are bronzed; but what we are faced with in the industry is not a striving for perfection alone but for perfection along the lines of efficiency. By putting this dusting unit into the bronzing machine, we can get much cleaner work, and the next day it can be run through the varnishing machine without showing any bronze even on dark greens or blues, which would show it up if it were there. So the four-cylinder vacuum bronzer answers the question of high speed and a clean sheet in the bronzing machine in the same operation.

Executives have been satisfied to leave the bronzing work to more or less indifferent supervision. If one went out into the pressroom and saw dollar bills lying around on the floor, someone would hear about it. On the other hand, in the pressroom one sees sheets of paper costing a good many dollars, with several colors on them that have cost money, and if asked about it, they would say, "Why, of course, we must allow for some spoilage, some waste." If that department was given the same care that the presses are given, the results would compare favorably. Bronzing machines are not given the same attention from the mechanical departments as the other machines.

Then there is the question whether it is advisable to put the bronzing operation in a separate room. In many instances, especially in building new plants, provision is made to put the bronzing machine in a little "coop" by itself. That is a mistake because the impression is created that it is a dirty machine, and that it is put there so that it will not get the rest of the room dirty.

I believe the bronzing operation is perhaps the most important of any of the operations in the plant, and it ought to have the same care and the same supervision as the other equipment.

# The Art of Photo Composing, or Photo-Mechanical Imposition

By WILLIAM C. HUEBNER,[1] BUFFALO, N. Y.

THE advertiser or other customer who buys color-printing work demands a faithful reproduction of the object or painting or whatever it is that he furnishes as "copy." The printed representation of this advertised product or other article in color is intended to convey a favorable impression, and if it is a commercial article, to create a desire for ownership through effective sales appeal. The color reproduction accomplishes its purpose only when the finished edition is in precise register, with the component images united to tell the story accurately.

Commercial printers know well the general methods of printing, which are relief, intaglio, and lithographic or planographic.

Reproduction in quantity, or mass production, requires the making of duplicate plates in the desired number, these plates bearing the image or subject to be printed.

In relief printing these duplicates are made by using an intermediate means such as stereotyping and electrotyping between the original plate and the duplicate. In both of these methods the detail of the subject on the original plate is so changed by the transposition or transference through the matrices that it is not reproduced with fidelity. The expense and other accompanying economic factors make the use of either of these old methods of duplication commercially impractical for multicolor quantity reproduction under present-day requirements.

Intaglio printing has no satisfactory intermediate means for producing duplicate plates, because its technical requirements involve either flat plates or continuous-surface cylinders with the designs or images etched below the surface. The practical difficulties of making uniform and exact duplicates of these images, placing them in the desired positions on the form, and then preparing them for intaglio printing have prevented satisfactory commercial results. The lack of fidelity to the color "copy" and the lack of uniformity in the finished product have proved a disappointment to the large buyers of intaglio color advertising and to the producers of such color printing.

In lithographic or planographic printing the duplicate plates formerly were made by the old hand-transfer method. The operation of transferring the design from the original plate many times over to the press plate did not permit of fidelity and uniformity, because of the method involved, the materials needed, and the widely varying elements in the human factor.

Experience teaches that to be successful in color printing the register must be kept within a 0.003-in. limit of accuracy. In practice the press plate or form bears a multitude of definite images that may or may not vary in size and subject matter and that may be arranged in any number of relative positions.

Each one of the several necessary press plates or forms contains only the portions of the images that are to receive one color, such as yellow or red or blue; and the completed product, in order to receive all of the colors, is printed from a number of composed press plates, each one for a different color.

## Close Register Required in Each Detail

Satisfactory mass production of color work needs commercially perfect registration not only in each of the several color plates composing the completed image, but also in the spacing between the multiplicity of the identical images on each of these forms; and this precise register must be maintained in the relative positions of the various portions of the images on all of the color forms.

Another factor necessary to success is the fidelity of the printed edition to the proof from the original plates.

The amount of each color applied at each impression must be properly controlled, because the color inks are not applied in solid areas, but by the stipples or ink conveyors of the half-tone plates as very small, individual dots. In practice the number of these dots is constant and definite, but the sizes thereof vary in accordance with the amount of color required on different parts of the finished product.

Precise registration for the size and location of these dots or ink conveyors is needed on all of the component color press plates if fidelity of color effect is to be maintained between the printed edition and the original proof.

It is apparent that in stereotype, electrotype, and hand-transfer duplicating methods the final press-plate image for a given color is altered or removed to some degree from the original image by each intermediate step in the duplicating method used.

Each step that changes the size, shape, character, or location of the ink-conveying dots through mis-register alters the fidelity of the color value accordingly.

As said, the advertiser who buys color printing is seeking faithful reproduction of his color "copy."

In mass production of press plates to produce satisfactory color editions, the register is the outstanding factor to successful results. Precise register in the size and position of the ink-conveying dots, as well as precise register in the relative location and position of the images composing each form for the component colors, is essential to successful color editions.

## Mechanical Imposition

Photo composing or photo-mechanical imposition is a comparatively new art or a new branch of the art of printing. It is the art of making printing plates wherein original designs are photographed directly on the press plate from which the finished edition is printed.

Photo composing or photo-mechanical imposition supplies the means for making a composed press plate or a series of them for use on printing presses whereby the images are applied in predetermined register directly to the press plate, in any size, location, or position and without any intermediate duplicating means.

The art of photo composing combines upon one press plate or a series of plates the images produced by the numerous processes of reproduction known in the three general methods of printing.

The results are obtained by exact mechanical means and the use of predetermined register which permits the making of commercially used press plates for commercial printing presses, from which better color printing is obtained and longer editions are secured, with greater satisfaction and profit to the user of color advertising and the producer of color printing.

The results attained by photo-composed plates indicate the wide range of work that can be done economically in black and

[1] Secretary and Manager, Huebner-Bleistein Patents Co.

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white or color, using typographic or lithographic originals, as well as varied processes.

All sizes of work, from cigar labels and stamps to large posters, including type forms with illustrations, are photo-composed successfully.

Photo-composed plates are preferably used on offset presses, producing better editions in less time than can be done on typographic presses or direct lithographic presses.

The producing of better editions, at less cost and in less time, is the reason why photo-composed press plates and offset presses are superseding the old methods of press plate making and printing.

### Mechanics of Photo Composing

Photo composing is accomplished by both methods of photography, by projection through a lens and by contact printing.

The projection method is used in the production of negatives intended for use in the contact printing machines. These negatives may hold two or more of the same image, repeated or combined with other images, forming group negatives.

The contact method is embodied in photo-composing machines, which produce the press plates on zinc or aluminum or on other desirable printing surfaces.

Twenty years of intensive application to practical work in going plants has developed four types of photo composers. These are being used for all kinds of work, of varied character and sizes.

The general functions of the various machines involve an image or negative carrier and a sensitized-plate carrier, relatively moved in one plane at right-angles. Clearance movement is effected by mechanical means to permit free travel to exposure locations without rubbing or damaging either the image plate or the sensitized surface.

Light action by an arc lamp is directed through an opening in the negative holder and passes through the light-conveyor openings of the negative for definite exposure periods. These exposure periods are limited by a motor-driven exposure controller so as to produce uniform results governed by light factor instead of time factor.

Close contact between the image and the sensitized plate to exclude any side light is forced either by direct mechanical pressure or by vacuum pressure during exposure periods.

A predetermined register system governs the successful results of photo-composed plates. It provides a complete system for computing exposure, location, and position of all images composing the printing form.

This is done by the coordination of the travel lines of the sensitized plate and the image plate, with known centers and dimensions of the image itself and of the register area covered. Precise register with any computed predetermined exposure location is obtained by the use of Swedish precision gage blocks, staggered to produce a rack 64 in. long with 1-in. spaces. The inch is divided into thousandths, indicated on a dial micrometer, which functions accurately and independently in any given or selected inch spacing of the gage blocks.

A special predetermined register device is used to place images in exact register with the travel lines of the moving sensitized plate or negative carrier. The register device indicates the travel lines of the photo composer so that the operator can quickly, conveniently, and accurately position the image to the zero point of the system, for computing the exposure location.

Adjustments are provided to maintain the travel lines at precise right-angles to each other. Accuracy is proved and maintained by hairline tests; that is, a single hairline opening on the negative is exposed on the sensitized plate and repeated three times, forming a continuous line three times longer than the line opening on the negative. This test is applied to both longitudinal and lateral travel lines. This proves accurate right-angle alignment, and provides the actual travel lines to which the predetermined register device is coordinated.

### Chemistry of Photo Composing

The chemistry of photo composing is so controlled as to produce durable printing conditions on the surface of the press plate.

Oxide coatings on metal plates are removed, and the surface is then neutralized as to acid or alkaline conditions. The surface is then rendered sensitive to grease by a sub-sensitizer solution, then sensitized with a coating for light action, and then dried. All this is done on a coating machine known as a whirler.

After exposure to the negatives the surface is coated with a greasy solution so balanced that when the solution is dry it will permit water to reach and dissolve the light-sensitive solution not acted upon by light. After development the printing plate surface is desensitized to grease by special solutions. These produce the printing condition needed by offset or planographic printing; that is, the image parts or dots accept ink from the ink rollers, and the grease-repellent surfaces of the plate surrounding the dots or ink-receptive parts accept moisture from the dampening rollers.

By carefully observing the rules governing the chemical action of a photo-composed plate on an offset press, successful editions up to 200,000 and more are printed, and a high quality of work is maintained at lower cost than by other printing methods.

Comparison as to time and costs of the old duplicating methods of stereotyping, electrotyping, and hand-transfer shows that photo-mechanical imposition or photo composing has the advantage of producing the work formerly done by all three methods in less time and with better quality, and certainly with lower costs in press plate making; and this augments the advantages in speed and lower costs of the offset-printing method.

Photo-mechanical plates, printed on offset or similar presses correctly coordinated, if the work to be done is intelligently planned, directed, and executed by trained operators, can lead the way in economical mass production of color printing, and in time will lead the way in text printing.

## Discussion

Edward B. Passano.[2] There is one statement in the paper which in my opinion should be qualified. The author states: "In relief printing these duplicates are made by using an intermediate means such as stereotyping and electrotyping between the original plates and the duplicate. In both of these methods the detail of the subject on the original plate is so changed by the transposition or transference through the matrices that it is not reproduced with fidelity."

It is the experience of the writer, and, generally speaking, it is the experience of the industry at large, that when a matrix is made by the lead process the electrotype is such an accurate reproduction of the original that there is no perceptible difference between the results obtained in printing from it and from the original engraving.

### Author's Closure

The author has no fault to find with that statement. It would apply to electrotyping just as it applies to hand transfers. There are thousands of hand transferers who think they can show better work than that made by machine. In fact, one man employed by the Methodist Book Concern says that he can make an electrotype that is better than the original. It is all relative; for in-

[2] President, The Williams and Wilkins Company, Baltimore, Md. Mem. A.S.M.E.

stance, if you are going to make a number of small repeated subjects, and if it is a matter of dollars and cents, you try to make eight or ten electrotypes exactly alike, so as to produce the edition economically. The photocomposer can do it better. However, there are varying limits in certain factors that creep into actual production of a series of repeated plates. I have never seen a set of, say, ten electrotypes made from one original plate that were exactly alike. They were close, but they were subject to criticism, especially in size, due to variable shrinkage in production of the individual electrotypes. Now, if you had a plate, say 12 by 14 in., on which groups of small subjects had to be accurately registered, and you followed the practice of electrotyping individual cuts and soldering them together, and from that grouped plate making a set of large electrotypes, it would be quite a job; it would take a lot of time, and that operation costs money.

In photocomposing we expose the required number of originals directly on the copper plate in exactly the position where they are needed, head up, sidewise, or head down in location. When that group photocomposed plate is finished, you make an electrotype of it, and there you have the advantage of speed, precision register, uniformity of result, and low cost.

We do not say we can make full-size press plates by photocomposing methods for the typographic press. In electrotyping there are limitations in size. We refer to the standard size of electrotypes for maximum size subjects that can be handled advantageously. We do say it is more economical to make a group of small subjects by photocomposing them than to group them by individual make-ready or soldering them together to produce a group plate and then making electrotypes from that group plate.

Just recently we decided to supply a small photocomposing machine for the photoengraver. The machine is about 4 by 6 ft. in size, mounted on one pedestal support. The photoengraver can then make small subjects in groups either directly on the copper or zinc plate or he can make contact group negatives for use in catalog color pages, small labels or small cartons from the photocomposed group plate. The electrotyper can make electrotypes for the printer which will save time in make-ready, and the results on the printed sheet will be more accurate than if the same job were produced without the photocomposing method.

If the photocomposer is used as intended, it cuts down make-ready time and eliminates the difficulty of assembling and registering a group of small originals or small electrotypes.

As to hand transfers, the author has seen some very good hand-transfer plates made by clever men, but it is not the usual thing. The difficulty with hand transfering is not only in getting the ink conveyors to correspond in size with the original plates, but in maintaining the size of the entire subject. There are other things to contend with; transfer paper varies the size of impressions with varied pressure when the impression is made. Hand transferring involves pulling impressions from various stones or plates.

In each case the pressure must be judged by the operator, and often there is a matter of days of time between the start and the finish of the job. I have never seen a hand-transferred plate that would take the place of the original plate, regardless of whether the sizes were alike.

# Report of Research and Survey Committee of the Printing Industries Division

## Organization Is Suggested of a Large Council of All Technical Men Interested in the Printing Industry to Discuss the Research Field in All Its Ramifications

By ARTHUR C. JEWETT,[1] PITTSBURGH, PA.

ON BEHALF of the Research and Survey Committee of the Printing Industries Division, I wish to present for your consideration two things: first, a problem affecting the printing industry; second, a plan for its solution.

All here recognize the magnitude and extent of the printing industry and the great variety of its related interests; in machinery for plant equipment; in innumerable kinds of supplies, such as paper, inks, textiles, adhesives, metals, etc. The briefest analysis serves to show that in this field there awaits solution a vast number of problems concerning the improvement of material qualities and operating methods, and the standardization of grades and sizes of material and equipment, and of working conditions in the printing establishment. The opportunities for profitable research are almost unlimited. It is obvious that no one organization or agency would alone show much progress in comparison to this extensive field.

There are, however, scattered about America from coast to coast many organizations and individuals who are making a localized attack on this large field. These researches vary from the scientific and basic to the superficial and slightly organized. When all these efforts are considered, there is still more left to be done than has yet been attempted. At the same time there exists a considerable mass of uncoordinated and unrelated research data that might be very valuable to many who do not even know of its existence. The problem is to secure a coordinated attack upon the entire field of research in its relation to printing and to make available to everyone interested a classified and indexed record of all that has been done to date. A formidable enterprise most truly, but one that may be successfully undertaken.

When the World War was being waged and many nations were called together in a supreme effort, a unified allied command became an unavoidable necessity. There are now many important organizations interested in the results of printing research, only a relative few of which are actively engaged in such work. If all could be enlisted to do a part and a centralized body could be organized as a coordinating and directing headquarters, the problem could be solved.

Your committee considers that this is not a fanciful dream or even an impractical idea. Our age and our country are both of the sort which makes such things possible. As a start, it proposes that a meeting of all technical men in the printing industry be organized, and that this be upon the occasion of the meeting of the Printing Industries Division at the next semi-annual convention of the A.S.M.E. Indeed, this meeting, with your approval, might well be the semi-annual meeting of the Printing Industries Division. It is estimated that there are at least four or five hundred such technical men.

The program of the meeting should be so organized as to reveal the opportunities for research, the capacity for research, the need of coordination, and the organization of a centralized coordinating and record bureau. A willingness to cooperate, to exchange data, etc., should be brought about and various organizations should be asked to assist in this work. There is, for example, already a representative organization whose aid would be invaluable in promoting such a plan.

In all this broad field of research the work of this Society should take two directions:

1 That of promoting research activities in the production field, and

2 Of attempting to bring about a coordination of the work of various organizations and to record and index all research work which is being carried on and all research data which is available, giving its location.

So far as actual research projects ought to be fostered by the Society itself, it is the opinion of the committee that the work should be confined to the production field as more directly related to mechanical engineering. It is also considered of great importance that everything possible be done to emphasize the importance of research work and to bring it prominently before all those whom it may affect.

In closing we ask: Do you approve such a meeting, as suggested, of technical men in printing? Will you do your part to enlist the interest of those other organizations interested in printing in which you are members or of which your companies are members? The Research and Survey Committee requests your support and suggestions.

Being put as a motion and seconded, it was carried and referred to the Executive Committee of the Printing Industries Division.

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Presented at the First National Meeting of the A.S.M.E. Printing Industries Division, Rochester, N. Y., November 8 and 9, 1928.

[1] The personnel of the Research and Survey Committee of the Printing Industries Division is as follows:

Arthur C. Jewett, Chairman; Director of the College of Industries, Carnegie Institute of Technology, Pittsburgh, Pa.

Francis H. Bird, Professor of Commerce, University of Cincinnati, Cincinnati, Ohio.

James R. Blaine, Mechanical Engineer, Miehle Printing Press Manufacturing Company, Chicago, Ill.

Edward W. Dean, Chief Engineer, Duplex Printing Press Company, Battle Creek, Mich.

Don A. Johnson, Superintendent, Empire State Printing School, Ithaca, N. Y.

J. Horace McFarland, President, J. Horace McFarland Company, Mount Pleasant Press, Harrisburg, Pa.

Edward T. Miller, Secretary, United Typothetae of America, Chicago, Ill.

John Clyde Oswald, Managing Director, New York Employing Printers Association, Eighth Avenue and 34th Street, New York, N. Y.

James T. Peto, Mechanical Superintendent, The Press-Guardian, Paterson, N. J.

M. E. Powers, Printing Engineer, Pettingill, Inc., Chicago, Ill.

Edward O. Reed, Technical Director, Government Printing Office, Washington, D. C.

R. F. Reed, Director, Department of Lithographic Research, University of Cincinnati, Cincinnati, Ohio.

W. E. Sooy, Secretary and Plant Manager, Michigan Carton Company, Battle Creek, Mich.

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# Photography as Used in Color Reproduction in the Graphic Arts

## The Three-Color Theory of Vision—Making Photographic Materials Sensitive to Colors—Natural-Color Photographs—Color-Separation Negatives—Printing Processes—Modern Four-Color Printing Presses and Their Interesting Devices

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***Indications are that the demand for color in the graphic arts, produced by means of photography, will continue to increase, and this means that as the fundamental principles appear to be well established, further improvements will be made in machinery and materials and the skill in using them; and particularly in adjusting practice as closely as possible to theory, so that color reproduction, while maintaining the highest possible quality, will be produced more speedily and more economically.***

In order to cover his subject in the limits of a paper, the author must necessarily omit a great deal of detail. The need for condensation will be seen when it is stated that a recent compilation of merely the history of three-color photography is a volume of 747 closely printed pages, treatment of all photo-mechanical processes being reserved for a further volume.

Color is not an objective thing in itself, it is a sensation and purely subjective. In other words, we receive an impression of color by reason of the varying reflections and absorptions of the different wave lengths which constitute white light. These wave impulses affect the mechanism of our eyes and brain, and according to their differing frequencies give us the impression of color.

Our yardstick for color is the spectrum, which was discovered by Newton in 1666. A spectrum is produced by passing a narrow beam of light through a prism, which refracts and disperses it. As white light is made up of a number of differing wave lengths, these are differently refracted and each wave length has a different color. This is ultimate, as any further analysis of any part of a spectrum does not yield anything different. So all colors can be referred to the spectrum, as they must either consist of one of the pure spectral colors or mixtures of them.

When light falls upon any substance it is either totally absorbed, in which case the object looks black—for example, a piece of black velvet; totally reflected, in which case it looks white, as freshly fallen snow; or selectively absorbed—that is, some portion of the light is absorbed and the remainder reflected, this reflected mixture of the non-absorbed parts of the spectrum giving the characteristic color. Thus, grass is green because the major portions of the blue and red are absorbed, and the remainder which is reflected is predominantly green.

### The Three-Color Theory of Vision

The nature of the mechanism in our eyes that gives rise to color sensation when appropriately stimulated, is still the subject of investigation and dispute. The most generally accepted hypothesis is that our eyes have only three sensations, one being stimulated by blue-violet light, one by green light, and one by red light. When all three are stimulated simultaneously we get white or gray, according to the intensity of the stimulation, and of course nothing, or black, in the absence of stimulation. On this theory we see all colors from these three, either alone or in mixture. For example, when we see a yellow it is because both the red and the green sensations are stimulated at the same time together, and this result gives us the effect of yellow in the brain.

This hypothesis was put forth by Dr. Young in 1801, and was confirmed by Helmholtz and many others after him.

In order to prove that the three-color theory of vision was correct, three narrow portions of the spectrum were isolated, one each in the red, the green, and the blue-violet, and it was found that by means of these, either alone or mixed in suitable proportions, all the colors of the spectrum could be approximately matched, provided they were diluted with white when necessary. While it does not matter in the least in practice what the mechanism of the eye is, provided any color can be approximately imitated by one or more of three, either alone or in mixture, it was this theory that led Clerk Maxwell to reason about three-color photography and to take the first step toward the current practice.

From the very beginning of the use of photography—not yet a century ago, because it was in 1839 when the first daguerreotypes were produced—it was hoped that color might be reproduced by means of photography, but it was not until 1855 that the first definite scientific principle was enunciated by Clerk Maxwell, then an undergraduate of Cambridge University and only 25 years of age.

In a paper communicated to the Royal Society of Edinburgh in that year, Maxwell said:

> Let a plate of red glass be placed before the camera and an impression taken. The positive of this will be transparent wherever the red light has been abundant, and opaque where it has been wanting. Let it now be put in the magic lantern along with the red glass and a red picture will be thrown on the screen. Let this operation be repeated with a green and violet glass, and by means of three magic lanterns let the three images be superposed on the screen. The color on any point of the screen will then depend on that of the corresponding point of the landscape, and by properly adjusting the intensities of the lights, etc. a complete copy of the landscape as far as visible color is concerned will be thrown on the screen. The only difference will be that the copy will be more subdued or less pure in tint than the original.

In 1861 Maxwell had the experiment prepared with a bow made of colored ribbons at the Royal Institution, London, and said that given a suitable sensitiveness to the red and green, the reproduction would have been a truly colored representation of the ribbon. It was not possible to make a correct reproduction then because there were no such things as color-sensitive plates as there are today, for at that time they were confined to the use of wet collodion. Ever since that time the theory, while not unchallenged, has remained unshaken, and all our color practice is based upon these principles. And in order to attain to the present quality of color work there has been no change in the theory but a great deal of advance in regard to the materials used, particularly in the filters, in the color sensitiveness of the photographic sensitive plates, and in the skill of the users of these materials. The recently introduced "Kodacolor" process of

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making amateur motion pictures in color is precisely the same in principle as Clerk Maxwell's first experiment.

Photographic materials are sensitive only by reason of their absorption of light, which in some way not yet completely understood disturbs the equilibrium of the particles of silver halide and renders those affected by light in this way capable of development.

### Making Photographic Material Sensitive to Colors

The law concerning this is known as the Grotthus-Draper law, and states that "only those rays of light which are absorbed can produce chemical action." Now photographic materials as manufactured are none of them susceptible to the chemical action of light rays in the same proportions as our eyes. Generally speaking, they are much more sensitive to the violet-blue rays than to any others, whereas our eyes are most sensitive to the yellowish green rays of about wave length 550 $\mu\mu$. Photographic plates are also sensitive to the ultra-violet, which we cannot see at all. The wet-collodion plate with which Clerk Maxwell worked has at least half its total sensitiveness in the ultra-violet. In these circumstances the problem has been to make the photographic material sensitive to all colors as nearly as possible as the eye is sensitive to them. It should be stated, however, that provided enough exposure is given, any color can be recorded on a non-color sensitive plate. Even a wet-collodion plate will record red if exposed 7200 times longer than it normally is. This, however, is not practical, and so it was a great advance when it was discovered how the plate could be made to absorb green and red light rays.

In 1873 H. W. Vogel was making photographs of the spectrum on all sorts of plates. He had one plate from England which had been stained with a yellow dye in order to prevent halation, that is, light penetrating the film and being reflected back from both surfaces of the glass on which it was coated. Vogel noticed that this photographed the green, which other plates did not. He thought this might be due to the dye, so he washed it out and tried another photograph, and, as he expected, there was no effect then in the green. He then tried staining plates with other dyes and succeeded with several, and so introduced the first color-sensitive plates.

Since that time many dyes have been found which are suitable for the purpose, though more is necessary than the mere fact that the dyes will absorb light of the particular color it is desired to photograph. The dyes mostly used to make the commercial orthochromatic plates sensitive to green and yellow are eosin and erythrosin, the use of which was patented in 1883.

In 1903 a dye known as ethyl red was discovered by A. Miethe and A. Traube, and this was the first of the modern dyes produced especially for the purpose of sensitizing photographic plates and which have since become universally used to make our present panchromatic plates.

Dyes have also been developed which sensitize plates even far into the infra-red. Some of the best of these dyes have been produced in the organic chemical laboratory of the Eastman Kodak Company. But even when plates are as fully sensitized as we know how at present, they still do not photograph the spectrum or colors in the same degree of luminosity as the eye sees them, and so a filter to cut down the excess sensitiveness to which the plate is subject has to be used when we are making photographs to give a monochromatic rendering in true values.

In the case of three-color reproduction the filter is used to cut off all other colors except the one which it is desired to record; thus the blue filter transmits the blue but absorbs the green and the red and prevents them reaching the plate; the green filter transmits the green but absorbs the blue and the red; and the red filter transmits the red but absorbs the green and the blue.

As in most cases we cannot make color-separation negatives suitable for the preparation of printing surfaces direct from the objects themselves, such negatives are made from colored representations thereof, such as paintings in oil or water colors. But this is not so realistic as photography itself, so there is gradually growing up a practice of making natural-color photographs to serve as originals for reproduction by photomechanical printing.

### Methods of Making Natural-Color Photographs

There are at present only two main methods of making natural-color photographs: first, the making of three-color transparencies on glass such as Autochrome or Agfa plates—so-called "screen plate methods;" and secondly, the making of a photographic print on paper in three colors. The most successful of these so far are the three-color-pigmented gelatin prints ("carbon process") and the three-color "Carbro" prints. In the latter a bromide print is treated so that it insolubilizes the pigmented gelatin-carbon tissue where required. Lastly there are imbibition methods such as the Pinatype and Jos-pe, in which a gelatin surface is dyed in proportion to the exposure and such dyes are imbibed from the respective three plates by a plain gelatin-coated paper in exact superposition.

To get good three-color paper prints is at present extremely difficult. They are therefore very expensive and as yet have not come into wide use, so that, as said above, most of the colored illustrations seen in magazines and books are reproduced by photographic means from artists' originals.

The transparency processes are called "additive" processes because they add the three colored lights together, while the color prints on paper are called "subtractive" processes because, starting with the white paper reflecting all colors, the dyes or pigments placed on it "subtract" from these the color not required. All photomechanical color processes are "subtractive."

### Color-Separation Negatives

To reproduce any object or a painting in its natural colors, it is necessary to make what are known as color-separation negatives. That is, a photograph is taken of all the reds reflected from the object, another of all the greens, another of all the blues. Frequently a fourth photograph is made giving a monochrome representation of the object with all the tones in their respective luminosity values, for printing in a black or gray. This is not actually necessary for color reproduction, but is doubtless done to save the trouble which the extreme exactitude of three-color demands. Small errors are covered up by the black plate, and so it is generally used. And when black text has to be used with the illustration it can be excused.

From these separation negatives, positives are made, and from these positives, negatives have to be made that are suitable for making a printing surface—though in the case of some printing processes the original separation negatives will do, e.g., collotype or photogravure.

When the printing surfaces are prepared they are printed in inks which are complementary to the recorded light. Thus the printing ink for the red record is a "minus" red, or green-blue; that for the green record is a "minus" green, or red-blue (magenta); and that for the blue is a "minus" blue, or a red-green, which is a yellow. The reason for these "minus" colors may be better realized if we consider a black-and-white photograph. The record on the negative is of the white of the subject photographed. This negative is now printed on sensitized white paper. The density of the negative representing the whites prevents light from reaching the paper so that it remains unchanged, but the transparent parts of the negative representing absence of white allow light to go through and darken the paper there. In other words, we have an absorbing material for white, or a "minus" white.

These color inks should not only completely absorb the colors which have been recorded by the photograph but should also completely reflect the other regions of the spectrum since some other color may have been present on the original. No such ideal inks are available as yet, and it seems doubtful if they ever will be. In order to correct the errors shown in any purely mechanical reproduction by reason of the imperfect inks or other cause, retouching by hand has to be resorted to, and this is what makes color reproductions so expensive.

### Printing Processes

Printing processes can be divided into three classes; (1) the most common, *relief*, that is, the familiar halftone and all letterpress printing; (2) *intaglio*, which is the exact opposite to relief, the design which prints being cut into the surface, represented by rotogravure and rotary rotogravure; and (3), *surface*, represented by all planographic processes such as collotypy and photolithography.

The taking of the original negative is the same in all these methods, but according to the process desired a departure is made in preparing the printing surface.

In the case of relief printing the effective gradation of tone has to be secured by means of ink of the same strength wherever applied, put on to a paper ground of one color only. Therefore the effect of tone can only be secured by varying the distribution of ink as compared with the paper. This is attained by splitting the picture up into minute dots which vary in area according to the tone required. Thus in a light tone the ink dot is small and much white paper shows. In a middle tone there are about equal proportions of ink and paper, and in a shadow tone the dots are large and the amount of white paper showing is very small. In order to produce these dots the negative is made behind a cross-line screen so placed in the camera that the amount of light reflected from the original at any point is represented by a correspondingly sized dot. The dots are so small they cannot be individually distinguished by the naked eye, but appear as blended tones. The same sort of negative is produced for the planographic method, but the intaglio method is different because the effect of tone in this case is secured by varying depths of ink for varying tones, so that in the shadow the ink is piled up and in the high lights there is scarcely any. Most paintings and small objects without much relief can even be reproduced "directly" by using the color filter and the cross-line screen at the same time so that the one negative is both color-separated and grained ready for preparation of the printing surfaces without the intervention of a previous negative and positive; but this cannot be done with subjects of much relief or having very great contrast—they must be photographed in two stages.

When the printing surfaces are secured by whatever method, they have to be printed very exactly in register. The usual order of printing is the yellow first, the red second, and the blue last. The reason for printing the yellow first is because the yellow is a more opaque ink as a rule than the other two, and theory demands for the best results that the inks should be absolutely transparent. As no inks whatever are completely transparent there is always a slight preponderance of the last printing, and it is better to have a preponderance of blue for most subjects than a preponderance of red. If the average yellow ink were printed last it would blot out the other two colors, and there would be very inefficient reproduction.

### Modern Four-Color Printing Presses

In latter years, owing to the speed with which the work is required, inks have been developed that print wet, and the paper goes in at one end of the machine and comes out at the other completely printed. The most notable of these machines are those at the Curtis Publishing Company's plant in Philadelphia. These are the large four-color Cottrell printing presses which print the *Saturday Evening Post* and the *Ladies' Home Journal*. These presses are most remarkable ones as they are so built that they take the paper from the web and carry it on through the press on the impression cylinder, and impressions are made from the yellow, red, blue, and black plates, one immediately following the other. These presses run at about 55 revolutions a minute. In the new type they carry two sets of plates, giving a much larger production. They have a great latitude since they are always available for running black on each side of the sheet, or two colors on each side, or two colors on one side and four colors on the other. It is necessary to have an ink that is absolutely correct for this type of press, the yellow being tackier and having the ability to pull the red ink from the red plate, the red tackier than the blue, and the blue tackier than the black. This ink condition is one of the very vital points. Formerly great difficulty with color printing wet was the trouble experienced with offsetting when the sheets came off. But there is a most ingenious attachment to this press which prevents that. As a finished sheet comes through it is coated over with an extremely fine spray of liquid paraffin. This immediately solidifies, and when the next sheet is delivered it rests upon a minute amount of paraffin rather than on the ink, and so there is no offset. It took some time to adjust this accessory arrangement to the exact amount of paraffin necessary, but now it is so used that it does the work without any disadvantage whatever.

All the plates for printing by this press have to be specially prepared in regard to their overlay and underlay. The electrotypes must carry the treatment themselves to take the places of make-ready that would be necessary on the ordinary printing press, because each plate strikes the same spot on the impression cylinder. This treatment consists of lowering the lights of the electrotypes by means of paper-cut matrices impressed into the electrotypes while they are quite hot.

### Rapid Growth of Color Printing

Another point in regard to printing color work or indeed any halftone work is the very much greater need in it for accuracy and precision. An engineer, Mr. Claybourn, of Milwaukee, who has devoted many years to demonstrating this, is building presses now which, if the halftones and electrotypes have been accurately made, will give perfect results without any make-ready at all. The growth of color work in recent years has made necessary all these improved printing presses, and, although one hardly realizes it, the growth has been really astounding. For example, the editor of the *Saturday Evening Post* recently stated that in 1917 that journal carried only 417 pages of color advertising, whereas in 1927, ten years after, it carried 2864 pages. The *Ladies' Home Journal*, another of the Curtis publications, carried only 198 pages of color advertising in 1917, whereas in 1927 it carried 719 pages. Four-color was first used in the *Saturday Evening Post*, October, 1924. In 1927 it carried 869 pages in four colors. Color reproduction is extending in all the other magazines in exactly the same way. In fact, there would be extremely little of it at present but for the application of photography to the problem. The various hand processes, wood engraving, lithography, or mezzotint or stipple, in color, are all too slow and costly to the modern idea, besides they do not give the realistic impression that photography does, so that almost without exception the colored reproductions which we see everywhere in such increasing quantities all depend upon photography.

As our knowledge becomes more widespread, there is an attempt to produce inks nearer to the theoretical requirements and also to use them in a standardized way. Hitherto many

ink makers have had their own standards of ink, and many engravers have used whatever inks they thought would give the nearest approach to the colors of the original with the least work on their part. Naturally, when a printer receives a number of engravings from different firms and different inks have been used, he cannot get a satisfactory result from all of them if they are printed together on the same press. This has been so disappointing to the advertisers that at last they have joined forces with the American Institute of Graphic Arts, which has had this subject under consideration for many years, and they are now insisting upon standard three-color inks being used. Though these may not be ideal, or the best that could possibly be obtained, it will be a great deal better to use them than to employ various kinds of ink and get various results in consequence when printing in different publications.

So far the author has dealt mainly with relief printing, but the same principles apply to planographic printing (offset, lithography, collotypy) and intaglio (photogravure and rotary photogravure).

### Interesting Devices Developed for Color-Printing Machinery

The increase of color reproduction has led to the development of remarkably interesting machinery in these processes, particularly the step and repeat devices to multiply the images in the reproduction of subjects requiring very large editions, as is often the case in lithographic printing. Sometimes these devices are cameras which can photograph the same thing many times on one plate, but more usually they take the form of machines which enable the same negatives to be printed on a large printing plate several times in the exact positions required. These machines have to be of the utmost precision in order that the color prints shall accurately register one on top of the other when printed on the press, and enormous effort and large sums of money have been spent on perfecting them.

Color has been applied to rotary photogravure for over a dozen years, but it has not become very common so far. Some newspapers, notably the Chicago *Tribune* and the New York *World*, use it in their Sunday supplements, and sometimes very successfully; but the difficulties in securing exact register due to the processes used in preparing the copper cylinder and printing from the web are very great, and it is also difficult to secure approximate fidelity to the original owing to the nature of the inks without excessive retouching, which is expensive and time consuming.

The indications at present are that the demand for color in the graphic arts, produced by means of photography, will continue to increase, and this means that as the fundamental principles appear to be well established, further improvements will be made in machinery and materials and the skill in using them; and particularly in adjusting practice as closely as possible to theory, so that color reproduction, while maintaining the highest possible quality, will be produced more speedily and more economically.

# The Field of Lithographic Printing

## A Brief Survey of the Various Processes, Materials, Machinery, and Operating Methods Employed in Lithographic Printing, With Special Reference to Multi-Color Work

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IN THIS age when color is king and is reflected in every article which we purchase, the demand for lithographic printing has grown by leaps and bounds. Color causes reactions which penetrate to the subconscious mind, creating a desire on the part of the individual to possess. With the presence of interest caused by color and word pictures, action prevails, and the effect is their urge to buy.

Window trims are more colorful, the attire of the nation's ladies is made more attractive and beautiful, the decorations of the product of the automotive institutions are a delight and harmonize with this age of contrast. By the use of lithography and color printing our advertisements are a distinct charm. The food containers on our grocers' shelves, with the colored reproduction of their contents, represent a condition which is entirely psychological. However, the housewife would not think of purchasing a commodity having a simple label, notwithstanding the fact that the contents of the container having the simple label may be superior to those of its gaudy companion. There is a possibility of the situation's being overdone, however.

The graphic arts have had a serious problem before them to keep pace with the desire for gaudily dressed containers and the blaze of color connected with advertising. At the present time there is an appeal for reform to eliminate the riot and reduce the problem to a sound and economic basis. The desire for innovations and the madness for style is leading to a condition due to freakish shades and tints that is baffling to lithographers and ink makers. A reform in this direction would be a material asset, and would greatly improve the economics of the situation.

### The Invention of Lithography

The invention of lithography by Alois Senefelder, who was a studious and ingenious man, was an achievement upon which the lithographic industry of the present day is based. The fundamentals of the art still exist notwithstanding the development of high-speed offset presses and photo-composing methods.

Senefelder was a restless genius and an experimenter dabbling in hundreds of different ways. First he practiced reverse writing. Afterward he found that by writing with an English pencil on suitable paper he could offset his writing on to stone. Having the stone for his original he was able to transfer the image to other mediums and multiply the creation. Finding a suitable transfer paper was one of the difficult problems he had to solve. Next in line with Senefelder came the problem of a proper printing press for the development of his work. The first press resembled a washing machine, involving a wringer or roll and a handle. From this crude beginning we have an industry which ranks eighteenth in importance today. Due to Senefelder's invention and the desire for color, the market for lithographic products has been created.

The question which comes to the mind of the average layman is this: Why the necessity for lithographic printing when color reproduction can be successfully accomplished by letter press? The principal reason for the existence of lithography is that on account of printing from a zinc or aluminum plate of large size (45 in. × 65 in.) it is possible to produce large quantities of beautiful work cheaply. One of the serious drawbacks to multi-color printing by letter press is the costly "make-ready." Preparing the lithographic plate is much more simple, particularly by the use of photo composing, step and repeat machines, or mechanical transfer.

### Lithographic Methods

A lithographic printing institution comprises a creative department where beautiful designs are developed and offered to the market; a photo-composing or hand-transfer department where these designs are reproduced for commercial production on the printing plate; and a printing department where by means of the planographic press, the image is reproduced in large quantities. The planographic process, which is described later, depends on both attracting printing ink to the parts of the image where it is required, and repelling it, through the antagonism of grease for water, where it is not wanted.

### Man Power

Beginning with Senefelder's invention in 1796, a craftmanship has been developed which has reached a high state of perfection. These highly trained artisans have been imbued with the pride of achievement, which is a very desirable attribute and reflects the standard of the institution with which they are affiliated. It is doubtful whether this profession will ever be materially affected by the development of modern methods, or replaced by the camera or by mechanical and other means.

This is, however, only as regards the creative function of the art, for in the production end of the business it is possible that the personnel may succumb to the ills of mass production. By that the author means that we shall develop press operators, cutting-machine operators, inspectors, and such employees as are concerned in handling the equipment, but due to proper control methods the preparatory work will be taken care of by other means. Under the present system the lithographer handles most of the details. Under the new scheme of things he will be familiar only with the specific function with which he is identified. The pride of achievement may be lost in the transition, and it will then be necessary to offset this condition by training. Executives are realizing at the present time the necessity for training, and arrangements have been made with the principal seats of learning in our leading cities whereby foremen, craftsmen, and executives may be afforded instruction in their particular branches.

### Production Control and Wage Incentives

In the reproduction departments, however, modern production methods have made some inroads. The lithographic industry has been very slow to adopt scientific management, and the majority of establishments are still functioning under the older methods. This is particularly true in connection with all departments except the mechanical. In the press field considerable progress has been made.

Due to the severe competition which prevails at the present

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time and which will continue to command extreme effort, wage-incentive systems and production control will be necessary if the individual plant is to survive. The trend at the present time is to utilize photo-composing methods, high-speed offset presses, and long runs providing the greatest area of salable product with the minimum of waste.

The industry has been slow to adopt material-handling methods and as a consequence there are great possibilities in adopting the Ford plan and thus increasing production per man-hour many fold. In order to adopt these measures, however, it will be necessary to practically revolutionize the industry. It is the tendency at the present time to carry large inventories of raw and semi-finished material requiring a large investment and much floor space. This condition prevents a rapid turn-over of capital and is a serious handicap in the competitive market. Most of the establishments have developed from a modest beginning and as a result it was not possible for them to give any thought to the flow of raw and finished materials or to building layout. To remedy this situation will require a comprehensive study of methods to eliminate large inventories and excessive floor space. One of the serious drawbacks to the continuous-flow system is the large floor area required for stock in process. Where presses are running in series on a color program the proper coordination of the colors involves a time element necessary for the oxidation of lithographic inks. It would be necessary to overcome this condition by the adoption of conditioning apparatus to promote continuous flow of materials and oxidation of inks.

Proper plant layout is one of the prime essentials if a production-control system is to be inaugurated, and offers an opportunity for the engineering profession to develop the field. It is only recently that sound engineering principles have combined with inventive genius. The modern press is constructed by the aid of jigs and fixtures, the result being that the parts are interchangeable. This was unheard of a few years ago. With the adoption of modern methods within the industry the problems of foreman training and human development will become much more pronounced.

One of the basic materials upon which the lithographic industry depends for its existence is paper composed of cellulose fibers which are hygroscopic in nature and which relies upon the uniformity of the moisture content of the atmosphere to preserve its fitness for the process. It is advisable for the engineer to utilize synthetic weather or air-conditioning systems embodying refrigeration. One of the serious problems that the lithographer has to face is the expansion and contraction of paper fibers due to the variation in the relative humidity of the atmosphere. This condition is most serious during the months of July and August when the outside dry bulb is high. Without the use of an air-conditioning system and refrigeration apparatus considerable loss in production is experienced. This is also a contributing factor to the waste problem. It is often quite necessary for plants which do not utilize conditioning systems to shut down on very humid days. During the winter months, however, a reverse condition prevails. Where extremely low relative humidity exists on account of the necessity of heating the buildings, an air-conditioning system is a tangible and profitable investment and can be utilized practically during the entire year.

The tendency at the present time is to condition the paper warehouse or storage room, maintaining a uniform humidity and acclimating the incoming paper stock to that condition by individual paper-conditioning or curing machines. This element of production control is further augmented by maintaining the same relative humidity in the press and other process departments. The use of such equipment, however, is not a cure-all. There are a number of other variables which offset the situation. One of the conditions which has a bearing on the problem is the mechanical stretch of the paper and this is more pronounced in connection with the direct printing process than with the offset method. The offset press, however, has reached a much higher state of development and the coordination of printing surfaces is under a much better control than that effected by the direct-press method.

## Materials

As stated before, paper is one of the principal basic materials used in the printing industry, and exists in a number of forms carrying the trade names of book, blotter, tissue, board, bristol, manila, and others. These in many cases are subdivided into grades and classes. One of the necessary requirements for lithographic printing is a paper having a smooth surface and uniform thickness. This is accomplished by the use of paper calenders. In order to provide the proper printing surface it is customary in many cases to coat the surface of the paper with a material composed of china clay, blanc fixe, casein, and other coating ingredients. This coating process creates an ideal printing surface. However, many times it is difficult to secure a perfect impression on account of tinting trouble, particularly in connection with presses which print four or five colors at the same time. It is necessary to develop special coating materials for this condition. Second in importance in the line of materials are inks, the variety of which depends upon the degree of standardization of colors. An institution producing art subjects will apply as high as twenty colors to secure the necessary color values according to the temperament of the artist, while the regular commercial house usually standardizes on a maximum of eight or nine.

The colors are divided into groups as follows:

*Yellows*
1 Chrome Yellow
2 Chrome Orange
3 Yellow Lake

*Blues*
1 Milori
2 Prussian
3 Bronze
4 Ultramarine
5 Blue Lakes
  *a* Peacock
  *b* Oriental
  *c* Alkali

*Greens*
1 Chrome Green
2 Green Lakes

*Reds*
1 Mercury Vermilion
2 Red Lakes
  *a* Madder
  *b* Para Reds
  *c* Toluidines
  *d* Lithol Reds

*Purple and Violet Lakes*
1 Permanent
2 Fugitive

*Orange Lakes*
1 Persian
2 Permanent

These basic materials are used in conjunction with a large number of driers, reducers, softeners, and other substances which in compounded form produce the beautiful shades and tints used for the printing operation.

Paper and ink are two of the most essential materials used, but are supplemented by a large number of chemicals and supplies, such as chromic, nitric, and phosphoric acids, which are used as etches, rubber blankets, leather shins for covering form rollers, molleton flannel, canvas, rubber-covered rollers, gum arabic, stearin, photographic supplies, lithographic stones, etc.

## Machinery

Inventors identified with the industry for many years endeavored to duplicate by mechanical means the fundamental

principles developed by Senefelder and were successful in devising the stone press which followed in sequence the hand press. They applied a reciprocating motion to a movable bed designed to receive a large stone upon which the image was transferred in reverse. This bed moved back and forth underneath a cylinder which revolved in unison with it, and upon the periphery of which the paper was attached by means of grippers. To insure perfect register the gear and rack were coordinated by means of a stop tooth which came into contact with the rack on the bed. This allowed the bed to come to the same position each revolution. The stone press embodied the direct printing process and was the prevailing method used until the invention of the offset press by Ira Rubel in 1904. This invention was identified with the tin printing industry until about ten years ago, when it was adopted by the paper printer. The direct-printing method enjoyed a long period of prosperity, and utilization of this type of equipment was the medium by which the prominent lithographers of today established themselves. The process was highly developed and it became possible to print as high as five colors at one time. Two presses of this type were designed and constructed, and are in operation successfully today. Four presses were also built which would print four colors at one time. These are also in operation at the present time.

Lithographic presses are divided into two general types, direct and offset. The direct press is one in which the impression is made directly by the aluminum or zinc plate on the paper or medium upon which the design is to be printed, and is the oldest of the two types in general use today. The offset press is equipped with an additional cylinder called the "blanket" cylinder, upon which a rubber blanket is stretched over the printing surface on the periphery. In the operation of this press the image is transferred from the aluminum or zinc plate to the rubber blanket and in turn to the paper. By this method a more beautiful reproduction is possible, and as in the manufacturing of presses at the present time the tendency is to produce offset machines, the direct types will soon cease to be built.

The direct press has advantages where large quantities of ink are required for poster work or where a heavy background is desired on label work or jobs of this type. One of the drawbacks of the direct press was the absence of bearers, and without this medium the pressman had considerable difficulty in coordinating his printing surfaces. Another difficulty experienced in the operation of the standard types of direct presses was the method of sheet delivery. The early types embodied the fly delivery, which was fairly successful. The fly delivery consisted of a series of hardwood sticks ranging from 30 in. to 48 in. in length according to the size of the press. These fly sticks were tapering through their length and were equipped with steel star wheels at intervals of about 6 in., arranged in a vertical position on a horizontal axis in a slot. These sticks were supported at the base by a shaft which caused them to travel through an arc of about 90 deg. They received the sheet of paper from the delivery cylinder and delivered it to the pile where the sheets were stacked.

It had disadvantages, however, due to the fact that the work was delivered to the fly with the printed side down. Further, it was necessary to use fly strings on the delivery to carry the sheet down to the proper position for the fly sticks to receive it. These strings also contributed their share toward producing work of poor quality. This type of delivery was responsible for the slower speeds in the operation of these presses, and this condition prevailed for a number of years until the chain and gripper delivery was developed. This improvement embodied two methods of handling the material in process: First, the racking feature, where the printed sheets were delivered to a rack which was inserted under the delivery grippers. These racks held about fifty sheets, and were quite necessary on presses printing three or more colors on account of the danger of offsetting. This feature was also a material aid in the oxidation of the inks. Secondly, the possibility of stacking the work on platforms which could be handled by an elevating truck. This type of delivery required an elevator, which was embodied in the design of the press.

With the desire for greater speed the press builders developed the chain and gripper delivery, which is used by practically all press manufacturers at the present time. In most instances this increased the speed of the press, but the marking of the sheets still prevailed and a poor quality of work was produced. As in the former case, this was due to the fact that the work was delivered with the printed side down to delivery conveyor. The sheet was reversed finally and arrived on the pile right side up. Many presses of this type are in operation today, but they are not adapted to work having heavy backgrounds where high quality is required. This defect was overcome later, however, by the adoption of the extension delivery such as is used in conjunction with the modern offset press.

In the modern extension delivery the sheet is delivered from the impression to the delivery cylinder underneath the press; passes below the operator's platform and is delivered right side up on a platform for stacking.

In the older chain-delivery types, the sheet was transferred upside down from the impression to the delivery cylinder near the top of the press.

Competition in design was responsible for many improvements as the field developed. This was particularly accelerated by the use of electrical equipment which made it possible to employ individual drive, dynamic braking, inching, reversing, and other features. This also made it possible to trip the press automatically when a sheet of paper failed to register at the guide. Competition in press building was also responsible for the development of the automatic tripping of press cylinders and roller motions, which eliminated lost time and increased production.

Labor conditions and the desire for better register of colors created a field for the automatic feeding of presses, and at the present time this is standard equipment. The automatic feeder embodies many features which prevent lost time. It comprises several functions such as sheet separation by means of a platen, a lifting and forward movement by means of suction and pressure under the sheet, micrometer control to insure one sheet's being delivered at a time, a tripping device in case a sheet failed to come up to the guide correctly, as well as other features.

With the adoption of the offset press by the paper-printing industry a machine has been developed which embodies sound engineering principles and skilled workmanship. In the early days of the press builder the designer was usually more inclined to be an inventor than an engineer, which resulted in a lack of standardization. The offset press of today has been constructed for the purpose of mass production with a high standard of quality, quick make-ready, and automatic devices to eliminate lost time. It is possible to operate the latest types up to and including 4000 per hour. By the use of suitable bearers the printing surfaces are under control and slippage is practically impossible.

The possibilities in the offset-press field are unlimited and it would be difficult to predict as to developments in the future. Except in one or two special cases, two colors are the most that have been successfully used on the sheet-feed press. A German manufacturer has been successful in building a four-color web offset press which is in use at the present time in Australia, and one of the representative press manufacturers has expressed a willingness to build a three-color sheet-feed offset press for a special line of work. The various lines of machinery which are

involved in the finishing operations have also kept pace in improvements and automatic features.

The finishing process utilizes some of the following equipment: embossing presses, folding-box machinery, and scoring and creasing, stitching, and cutting machines. There has been a desire on the part of the cutting-machine designer to build a machine having greater accuracy and strength. At the present time German manufacturers are placing cutters on the American market which are massive in structure and embody automatic features such as spacing devices and adjustable clamping to allow for differences in thickness of the stock to be cut. A new safety trimmer has been designed which adapts itself very effectively to the continuous flow of stock. This cutter differs from the conventional type in that the stock to be cut is fed at the front side of the machine and delivered at the back. It is particularly successful in connection with the chopping operation.

Folding-box gluing machines have been developed which have a production as high as 700,000 boxes per day. Formerly 250,000 was considered a good record.

The scoring and creasing, stitching, folding, and other machines have been greatly improved to promote greater production.

### Research

Nearly all of the branches of industry which process or manufacture the raw materials used by printers are affiliated in some way with some institution involving research. The Pulp and Paper Makers' Association have identified their activities with the Forest Products Laboratory of Madison, Wis., a branch of the Department of Agriculture. The manufacturers of lithographic inks and the lithographers have subscribed to the Lithographic Technical Foundation. This is operated under the auspices of the University of Cincinnati and is directed by Prof. Robert Findley Reed.

The manufacturers of lithographic and spirit varnishes are either connected with some research bureau or conduct their own. This is true also of the manufacturers of the less important materials which enter into the operation of a plant. Paper, historians tell us, was made by the Chinese some five thousand years ago, and has been gradually improved up to the present time. Considerable research work has been conducted and constructive developments made. In spite of all this, the lithographer feels that the surface has hardly been scratched, and that the paper manufacturers have before them tremendous opportunities for advancement in the art.

In this age of automatic packaging machinery the label manufacturer has before him a serious problem to produce a label that will function properly. This involves paper of proper tensile strength, flexibility, folding quality, glue penetration, surface and absorption qualities, as well as better appearance. These requirements are severe, and in some grades of paper the character of the cellulose fiber plays an important part in the formation of the sheet. Paper manufactured from the northern woods has longer fiber than that from the southern woods, and in the manufacture of gum-label stock this is a very necessary requirement. The fiber formation and use of southern wood pulp provides a stock that will function on a high-speed gum-wrapping machine.

For can-label stock, to which spirit varnish is to be applied, an entirely different formula is required. In the light of these conditions and many others the paper-manufacturing industry has a need for continuous and extensive research.

Due to the depletion of our national resources—and this applies particularly to our forests—it will be necessary to find a substitute for wood fiber. Recently great strides have been made in the utilization of sugar-cane refuse for paper making. This is being offered to the trade at the present time. Reforestation naturally will play an important part in prolonging our supply of wood. However, substitutes will be a necessary adjunct. In the lithographic field much is now being done to improve and simplify the process. At the present time experimenters are endeavoring to make a printing plate that will last indefinitely. The average life of a plate at the present time is about 50,000 impressions, and there have been instances where a plate has produced as high as 500,000 impressions. This proves that under the proper conditions plates can be made that will compete with electrotypes. The lithographic process is over a century old, nevertheless the facts related prove that we do not have a complete knowledge of the subject. There are tremendous opportunities in store for the research chemist.

Some inventors have endeavored to create a process of dry lithography, but at the present time have not met with great success. Possibly the nearest approach to the goal is the new Pantone process, recently brought out in England. It is claimed that a plate produced by this method will last indefinitely. The announcement of the electrodeposition of rubber on metallic surfaces attracted considerable attention, but up to the present time it has not been a commercial success as regards the lithographic industry; however, it has possibilities in connection with better printing surfaces. Further opportunities are seen in conjunction with the photo-litho process, and we look forward to the time when the offset press and photo-composing methods will remove many of the difficulties which exist at the present time.

The manufacturers of paints and varnishes have conducted many experiments and tests dealing with the oxidation of linseed oil, and much valuable information has been obtained on the subject. However, great possibilities exist to further this important work which is so vital to the paint manufacturer. The lithographer is particularly interested, and his problems in this respect are serious and of great importance. The use of different pigments in conjunction with linseed-oil varnish results in oxidation processes which vary considerably as regards the time element. In order to expedite matters it is necessary to employ catalysts, which accelerate the processes by providing more oxygen to the molecules. This variation in oxidizing qualities is a serious problem for the printer, and affords great opportunities for improvement.

### Some Recent Lithographic Reproductions

One commercial-art subject which attracted much attention was the Mazda calendar of 1927. This represented the application of fifteen colors and tints applied by the offset method, and the average layman can hardly realize how it would be possible to utilize so many. This reproduction, entitled "Reveries," presents a beautiful garden and a sparkling pool of water from which rises a fountain beneath which repose two female figures representing youth in all its charm.

To produce this picture in the proper color harmony it was necessary to employ a large number of colors and tints, possibly four different blue tints, as well as several pinks, browns, etc. The Mazda calendars for several years, including 1928, it may be said, have been lithographic masterpieces.

One lithographer has been very successful in reproducing oil paintings by the great masters which defy the most skilled artist to select the original from a distance. These reproductions are on sale in the art stores and retail for as much as ten to twelve dollars each. They require many tints to secure the proper tone and color value.

Some of our advertisements are art subjects of distinction; for example, the one depicting a girl in summer attire and youthful beauty, calling our attention to the merits of a popular beverage.

Sometimes it has been necessary to utilize as many as twenty-two colors and tints to produce an intricate subject. These are rare cases, however, and unusual.

In the superimposing of colors in the planographic process it is customary for can-label work to print the less opaque colors first and follow in sequence with the more opaque; the first colors are the yellows and greens, followed by the dark blues, reds, browns, blacks, etc., according to the subject to be produced.

Great care has to be exercised in timing the application of the several colors. If the first colors become thoroughly dry before the succeeding ones are printed they will not lift properly; also the second application will not oxidize properly because the first colors become hard and eliminate absorption, in which case the later colors are on the surface and require a much longer time to become dry.

### Some of the Processes Employed in the Lithographic Industry

*Collotype.* The planographic field comprises several processes which are in use today successfully, one of the earliest being the collotype process, invented by Louis Alphonse Poteoin, a French chemist, in 1855. In this process a film of gelatin is prepared in such a way that it can be printed lithographically by being made selective to greasy ink and water. The gelatin is first sensitized with ammonium bichromate and given a grain on drying. It is then exposed under an ordinary photographic negative, washed and dried, after which it is treated practically the same as a lithographic stone, having closely corresponding properties. Another process quite similar to the collotype is the aquetone.

*Photogravure.* Photogravure or intaglio is a process of printing from a copper-covered cylinder on which the image is etched below the surface by means of acid, the tints and shadows being controlled by the depth of the etching and the halftone dots.

The copper plate for photogravure is first prepared with resin dust. A positive transparency is made from a photographic negative and from this a print on carbon tissue, which latter is then pressed down on the prepared copper plate and developed; following development the plate is etched with perchloride of iron solutions of various strengths. The etching will be deepest in the shadows and least deep in the high lights. In printing a shiny coated paper is used and an ink of light consistency. Surplus ink is removed from the surface of the cylinder by a scraper, the remainder being applied to the paper in the usual manner.

*The Pantone Process.* One development which some authorities feel holds forth great promise is the Pantone process, recently bought out in England.

In this process a very smooth sheet of iron or mild steel is successively electroplated with an exceedingly thin coating of nickel, a coating of copper about 0.006 in. in thickness, and a thin coating of chromium. The plate is further coated with photoengravers' enamel, exposed under a halftone negative, developed, and burned in. This procedure is followed by etching in glycerin and hydrochloric acid which eats away only the chromium. After this the plate is placed in a silver or gold plating bath, where metal is deposited in the recesses formed by the etching process.

The enamel is then removed and the plate rubbed with a mixture of mercury and chalk to amalgamate the silver or gold areas. This provides areas of ink-receptive chromium forming the blacks of the image, and amalgamated areas of ink-rejecting gold or silver distributed over surfaces of the plate and forming the whites of the image.

By using an ink compounded with a certain amount of mercury it is possible to produce a satisfactory impression. The originator claims that there are great possibilities in this method as it produces plates which will last indefinitely.

In conclusion the author wishes to state that future developments will undoubtedly make it possible to secure a million or more impressions from a planographic plate, which will make it a competitor of the electrotype. And with such plates in combination with the modern high-speed offset press, the future offers great possibilities.

As I see it, the lithographic field is divided into two or more groups: One where mass production can be applied, this involving the production of three- and four-color labels of various kinds, seed packets, children's books, and work of that nature; the other a group where art subjects are printed in smaller quantities requiring greater craftmanship and skill. It would be very difficult to apply production methods to this class. In the former case, standardization of materials plays an important part and the control of materials used so far as uniformity is concerned. In mass production applied to the industry, uniformity is absolutely essential and scientific instruments will and can play an important part. This concerns the paper medium, inks, chemicals, gums and the many product which are used in the process.

## Discussion

J. R. Blaine.[2] The author's treatment is concise and suggests several points where material improvement and advance can be looked for. Fundamentally, lithograph printing is planographic printing and as such has problems quite different from letterpress or raised-surface printing. The main difference is found in the printing contact on the sheet. This contact is theoretically a line contact, but in practice is really a surface contact extending the entire width of the cylinder and depending upon the amount of yield in one or the other of the contacting members, be it cylinder packing as in direct lithography or rubber blanket as in the offset process. This contact pressure comes over the entire sheet during the revolution of the cylinder no matter where or what the size of the design may be. It brings in to a much more vital degree the question of how the stock "lays." For this reason wrinkles, distorted sheets, and misregister are more common than in letterpress printing. These troubles can be minimized, as is done in some of the larger establishments where air-conditioning apparatus is installed, which keeps the temperature and relative humidity under constant control, in the pressroom as well as in the seasoning room.

Another problem in lithography which demands attention is the question of water. No doubt the greater percentage of printing trouble is directly traceable to the fact that water is as necessary as ink. That this is realized is shown by the attempts now being made to eliminate the water entirely by substituting an ink-repellent surface such as described by the author in the paragraph headed "Pantone process." So far, it can hardly be considered a success, as it is still in the experimental stage. Other experiments on extending the life of lithograph plates are being tried, and no doubt will lead to improvements which will increase the number of impressions many times over what is now possible.

This is the age of mass production, and nearly all industries, including the printing industries, are profiting by the experience of the automotive organizations. Modern presses are built for speed, and improvements are made to increase running or producing time. This is as it should be. However, the writer has felt that there is a lack of cooperation or rather of understanding between the artists, designers, and advertising men in that greater production, better quality, and consequently lower cost

[2] Mechanical Engineer, Miehle Printing Press and Mfg. Co., Chicago, Ill. Mem. A.S.M.E.

could be obtained if they were to study their designs and compositions in the light of just what the press must do in reproducing the subject. We all know that artists are temperamental, and perhaps that is the reason no one dares "take the bull by the horns," as it were, and tell them what to do. However, the advertising manager cannot hide behind this excuse, and it would seem that help might be expected from this end. It would be interesting indeed to know just how much running time is lost in a year due to the fact that the artist or advertising manager insists on some insignificant point or combination as regards color or register composition.

Winfield S. Huson.[3] The fullness of the author's paper invites discussion from several angles. It is in the closing paragraph, however, that the writer feels he detects an accentuation of a vista of the future on which the paragraph touches. It may seem idle speculation to dwell on the great possibilities spoken of; nevertheless, the tenor of the paper points to advancement and marked change in present method and practice.

To those who closely follow printing in its intricacies, every thought that conduces to application of new discovery and skilled investigation, particularly in the field of chemistry, senses itself in the broader thought that printing, as we know it today, must ultimately be produced through the results of laboratory research.

It may be, too, that these remarks seem irrelevant to the usual discussion that might be expected on so excellent a paper, but when one knows the circuitous ways of present practice in the preparation and production of printed matter, as pointed out, and then considers what has and is being done by photography—for instance, the recent demonstration of direct-color reproduction, also the chemical reactions as outlined in the paragraph on the Pantone process as showing satisfactory response to positive and negative attraction—and other research, it lends conviction to the view that planographic or surface printing is an able forerunner of the coming event.

The printed page will be produced from a plane surface on which the magic of light has been impressed in all the beauty of the chromatic spectrum, which as it is imparted to the printed sheet will be continuously built up by the response of selective chemical affinities to color tones.

How it will be done, the laboratory will find out. So do not be surprised if some day our literature comes to us in all the resplendence of color sensation, and the production raised to a bewildering quantity, all in one running through the press—if it is still called by that name.

The outlook may not be encouraging to the ink and the plate maker, but their work will not be lost in the scheme of things as we delve in nature's laboratory to uncover the elements and factors that will contribute to further high achievement in the everlasting art of printing.

[3] New York, N. Y.; Chairman, Progress Report Committee, Printing Industries Division. Mem. A.S.M.E.

Randolph T. Ode.[4] I would ask the author if, with air-control in the summer, does he still have trouble with the paper?

Mr. Van Vechten. According to the best authorities on the subject, we should not have any trouble if we maintain an average temperature or a moisture condition of the atmosphere throughout the year. In our experience, when the outside conditions are extreme, even when we have the inside conditions under control, the paper is affected to a certain extent.

Mr. A. J. Newton.[5] Is the inside entirely under control?

Mr. Van Vechten. So far as we can tell.

Mr. Ode. Have you found that it will help you materially in the summer time?

Mr. Van Vechten. Quite materially; it eliminates a number of days in the summer time when it is necessary to shut down due to very humid conditions.

Mr. Ode. Would you find any improvement in five-color operations when the job is begun and ended on the same operation?

Mr. Van Vechten. I think that is quite an improvement.

Walter E. Sooy.[6] Speaking of relative humidity, what percentage of humidity do you recommend for the air in the pressroom? Would you have trouble with static electricity if the proper relative humidity is maintained?

Mr. Van Vechten. We find that it does not when we carry a relative humidity above 45 per cent or somewhere in that neighborhood.

Mr. Ode. What have you found to be the correct humidity to use?

Mr. Van Vechten. We feel that the correct humidity is a point that never has been definitely determined. According to to the experience of other lithographers as well as ourselves we have selected a humidity that is in the line of economics and which can be maintained with the lowest possible cost.

Mr. Ode. You said something about 45 per cent.

Mr. Van Vechten. I said that the lithographer, the practical lithographer, preferred a low humidity.

Harold E. Vehslage.[7] Is that apt to vary from season to season, from winter to summer?

Mr. Van Vechten. Do you mean if we do not have control?

Mr. Vehslage. No; would you find the relative humidity should be higher in summer or in winter?

Mr. Van Vechten. It is better to maintain an average humidity throughout the year. That is why we selected 45 per cent as the most economical point to maintain.

[4] Secretary, Providence Lithograph Company, Providence, R. I. Mem. A.S.M.E.

[5] Engraving Department, Eastman Kodak Company, Rochester, N. Y.

[6] Secretary and Plant Manager, Michigan Carton Co., Battle Creek, Mich. Mem. A.S.M.E.

[7] Eastern Engineering Representative, Duplex Printing Press Company, New York, N. Y. Mem. A.S.M.E.

# Progress in Railroad Mechanical Engineering

## Contributed by the Railroad Division

Executive Committee: H. B. Oatley, *Chairman*, Marion B. Richardson, *Secretary*, William Elmer, A. F. Steubing, R. S. McConnell, and Elliott Sumner

As 1927 is the centenary of various railroad systems in this country, the recent and most elaborate celebration being that of the Baltimore & Ohio Railroad, it may not be out of place in this year's report to include a few figures which will briefly indicate the colossal proportions to which the American railway system has grown during the past 100 years.

The total investment in Class I roads now amounts to more than 24 billions of dollars; their mileage is in excess of 250,000, representing more than one-third of the world's total. On January 1, 1927, these roads operated 62,800 steam locomotives, which had an aggregate tractive power of 1,304,000 tons. As of the same date, these roads operated 2,350,000 freight cars which had a total carrying capacity of 105,717,000 tons. Over 1,000,000 cars were loaded each week during the year, and they carried 3791 tons of freight one mile for each inhabitant of this country. These figures give a background for an appreciation of the important place, in the economics of this country, which is occupied by our basic transportation industry. Lack of progress in development, and particularly in all of the engineering problems involved, would be a deterrent in the business and economic life of our nation. Such depressing effect, while it cannot be evaluated, would be admittedly enormous. A record of the progress which railway mechanical engineering has made, therefore, is always of value, and as the centenary of railroad beginnings is occurring, it becomes of more than ordinary interest.

During the past year the progress in railway mechanical engineering has been steadily toward bettering the operating efficiency of railroads by continuing the effort to increase the gross ton-miles per freight-train-hour. This unit is becoming generally recognized as a most valuable index. Part of the accomplishment is due to heavier and more efficient motive power, part to improvements in signaling, heavier car loading, etc.

"Railroad efficiency is a factor of national prosperity" has been a motto always in the mind of progressive railroad men. Efficiency in the purchasing and maintenance of stock material suitable for the requirements, but not involving an unnecessary investment, is an activity which, during the past year, has made marked progress. Intensive effort to avoid excessive surplus material has been made.

That some, at least, of the views expressed in previous reports of this committee have been brought into reality may be evidenced from the following quotation of a leading railroad executive:

> From the mechanical viewpoint, the most significant developments in the railway field are the design and construction of high-pressure steam locomotives, of oil-electric locomotives, and of very high-capacity electric locomotives; the application and operation of capacity- and efficiency-increasing devices to what may be called the normal type of steam locomotives, and the design and construction of locomotives of this same normal type so that they show more reliability in service, more economy in operation, and have a lower annual repair cost and a longer life.

The campaign for greater economy in the use of fuel, in which the International Railway Fuel Association and the Traveling Engineers' Association have been factors of great importance, has made progress during the present year.

The average daily movement per freight car for the first seven months of 1927 was 29.8 miles, the highest mark ever attained in any corresponding period, according to reports filed with the Bureau of Railway Economics. This was an increase of one-half mile above the best previous average established in the first seven months of 1926.

The campaign for greater safety, while not a mechanical-engineering problem, is of such intense human interest that endorsement of these efforts is not out of place in this report, and such endorsement is heartily given.

Progress in standardization of weighing equipment complying with the requirements of the American Railway Engineering Association and of the Bureau of Standards, has been reported as having made marked advancement during the current year.

### Motive Power

The tendency toward higher steam pressures in locomotive boilers is going forward, the Delaware & Hudson Company having put in service its 400-lb. *John B. Jervis*, and the Pennsylvania is engaged in designing a 2–10–0 type with 450 lb. pressure. Auxiliaries are operated with superheated steam; enlarged grate areas, and greater firebox volumes are being used in increasing numbers, as are also feedwater heaters and exhaust-steam injectors. Three-cylinder locomotives are being bought in considerable numbers.

Experiments are still being conducted with oil-electric locomotives in switching service. The Chicago & Northwestern have added storage batteries in order to reduce the weight of the primary power plant.

The effort toward long locomotive runs is continuing, and in this effort larger tenders and a better spacing of water stations are proving effective.

Cast-steel underframes for tenders are being more extensively used, and experiments are being conducted with one-piece cast-steel locomotive frames and, on one road, with a cast-steel smokebox.

There is increased activity in and development of a modified boiler construction permitting more satisfactory service, not only for use with higher steam pressures, but with consideration of better water circulation and the reduction of corrosion effects. Consideration is also being actively given to the proper adaptation of condensing operation as well as to the use of air preheaters.

Reference to Table 1 shows the marked increase in the use of four-wheel trailing trucks on locomotives. It is to be noted also that practically all of the new and advanced designs of locomotives constructed during the year have had this feature, and also that a large proportion of the new designs have been built for steam pressures ranging between 220 and 300 lb. per sq. in. The tendency in this particular, mentioned in previous reports, has been progressing during the current year. A number of the new designs of locomotives have made use of nickel, or silicon, alloy steel for the shell plates of these higher-pressure boilers. Reports of the service of this material have not shown any indications of difficulties, and the advantages in reduced weight for a given set of conditions appear to have been realized.

Indications, from the records covering the first half of 1927, encourage the belief that the fuel savings on locomotives will

TABLE 1 DATA ON NEW DESIGNS OF LOCOMOTIVES

| Road | Type of engine | Boiler pressure lb. | Cylinders No. | Cylinders Max. hp. | Type of superheater | Back-pressure gage | Feed-water heater or injector | Max. cut-off, per cent | Throttling between super-heater and steam chest | Grate area, sq. ft. Total | Grate area, sq. ft. Per 100 hp. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A. T. & S. Fe | 4-8-4 | 210 | 2 | 3150 | E | None | FWH | 88 | Yes | 108.4 | 3.44 | Mult. throt. |
| B. & O. | 4-6-2 | 200 | 2 | 2252 | A | None | — | 85 | No | 66.7 | 2.96 | ...... |
| Can. Natl. | 4-8-4 | 250 | 2 | 2705 | E | With | FWH | 85 | Yes | 84.3 | 3.11 | Mult. throt. |
| C. B. & Q. | 2-10-4 | 250 | 2 | 4000 | E | With | FWH | 65 | Yes | 106 | 2.65 | Mult. throt. |
| C. & N. W. | 2-8-4 | 240 | 2 | 2915 | E | With | FWH | 60 | Yes | 100 | 3.43 | Mult. throt. |
| D. & H. | 2-8-0 | 300 | 2 | 3121 | E | With | — | 75 | No | 99.8 | 3.19 | ...... |
| D. L. & W. | 4-8-4 | 250 | 2 | 3036 | A | With | — | 85 | — | 88.2 | 2.9 | ...... |
| D. & R. G. W. | 2-8-8-2 | 240 | 4 | 5100 | A | With | FWH | 70 | Yes | 136.3 | 2.68 | Mult. throt. |
| Erie | 2-8-4 | 250 | 2 | 3430 | E | With | FWH | 81 | Yes | 100 | 2.9 | Mult. throt. |
| G. T. W. | 4-8-4 | 250 | 2 | 2870 | A | With | FWH | 88 | Yes | 84.4 | 2.94 | Mult. throt. |
| I. H. B. | 0-8-0 | 205 | 3 | 2829 | A | With | FWH | 84 | Yes | 72.5 | 2.56 | Mult. throt. |
| N. Y. C. | 4-6-4 | 230 | 2 | 2580 | E | With | FWH | 86 | Yes | 71.5 | 2.77 | Mult. throt. |
| O. I. M. Co. | 0-8-0 | 235 | 2 | 2070 | A | None | FWH | 80 | Yes | 63.0 | 3.14 | Mult. throt. |
| So. Ry. of Eng. | 4-6-0 | 220 | 4 | — | — | — | Inj. | — | — | 33.0 | — | ...... |

amount to approximately $17,000,000 as compared with the year 1926. The consumption per 1000 gross ton-miles in freight service for the first four months of this year was less than for the corresponding period during the year 1926. If this rate of reduction is maintained, the 1927 figure will be 129 lb.

### Rolling Stock

Experiments are being made with lacquers for both the exterior and interior finish of coaches and dining cars.

A number of railroads are putting motor buses on the highways as feeders to, as well as paralleling, their steam routes. Larger and higher-powered motor rail cars have been developed to haul one or two trailers.

The rapid advance in the use of self-propelled cars is evidenced by the fact that over 200 of such units were purchased during the first half of the year 1927.

The American Railway Association standard box car has been designed, and plans are being prepared for hopper and gondola cars. One road is experimenting with a solid cast-steel underframe for freight cars. Improvements in refrigerator cars involve trials of the "silica gel" process and "dry ice" or solid $CO_2$.

Automobile cars of new design, embodying side doors 12 ft. in width, have been built by the Chicago, Milwaukee & St. Paul, the Missouri, Kansas & Texas, and other roads, to meet an urgent demand from automobile manufacturers for cars with wide side doors, so that easier loading of completed automobiles is afforded. Reference should be made also to the 70-ton hopper gondola cars put in operation during the past year by the Delaware, Lackawanna & Western Railroad.

### Economics

From the economic standpoint, we have the benefits realized by shippers and merchants because of the rapid and reliable movement of freight and passenger traffic; the rapidly increasing safety of travel, and especially the steadily decreasing net income of the carriers, which follows the many reductions in freight rates on the one hand and the alarmingly rapid increase in taxes and in payments to railroad workers on the other.

It is gratifying to note a change in public sentiment toward corporate interests, and particularly toward the railroads. A more sympathetic and appreciative viewpoint on the part of the public toward the progressive efforts of the railroads cannot help but have a beneficial effect upon all interested parties.

Greater efforts toward informing the general public of the engineering and operating progress is proving a wise move, and the railroad industry in general is to be commended for its efforts in this direction.

From the political standpoint, we have the growing political power of the standard labor unions; the desire of many politicians to stimulate railroad consolidation and to reduce freight rates, without regard to the cost of the service; and the thinly veiled designs of many to work toward Government ownership of the railways.

The increase in efficiency and reliability of the railroads, since 1920, has affected the every-day life of every individual. There have been no strikingly important changes in the machinery or processes during that period, although large sums of capital have been invested in the direction of modernizing and increasing the capacity of the railway plant.

Progress in extending the use of automatic train control, improved automatic signal systems, and more efficient operation in freight classification yards is also to be recorded for the year.

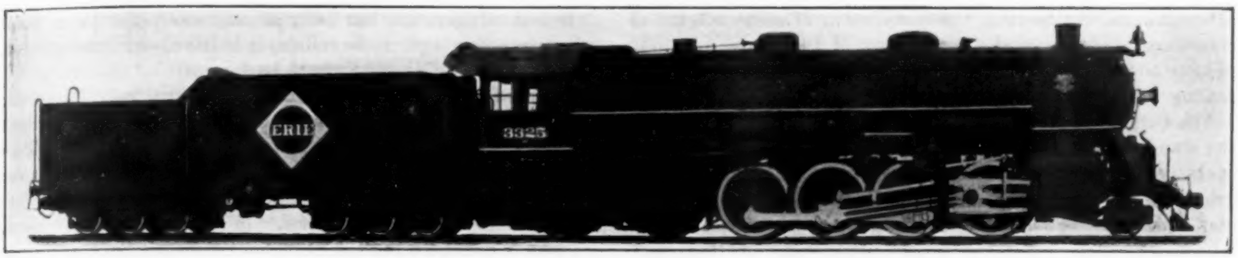
### Technical Training

Questionnaires were sent to all the technical schools and colleges that maintain courses designed to prepare students for railway-mechanical-engineering work. The replies show that the various educational institutions are beginning to feel the results of a greater effort on the part of the railroads and railway-supply companies to cooperate in the training of men for their respective industries. In addition, the American Railway Association has been utilizing the laboratory and test facilities afforded by the various educational institutions, especially at Purdue University.

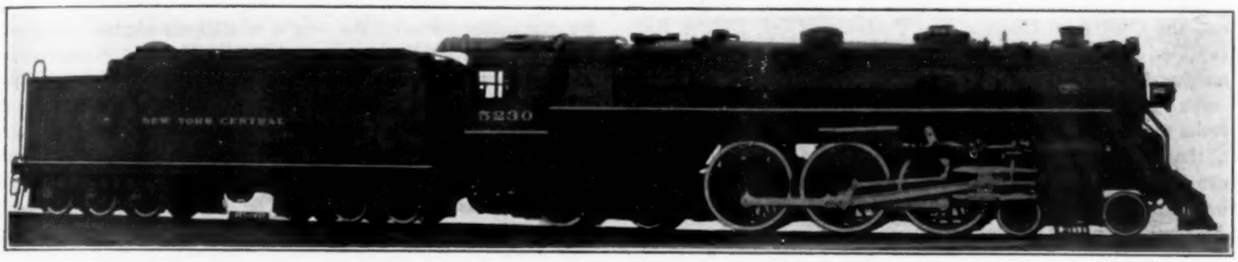
The Pennsylvania State College has for some time been studying the problem of insulation and heat transmission, factors in the efficient insulation and cooling of refrigerator cars and the heating of passenger cars. Considerable progress in this work has been made in the past year.

A number of radical changes are being considered in the courses of study offered to students in railway mechanical engineering. For a number of years past different institutions have maintained courses in their curricula leading to the degree of Bachelor of Science in railway mechanical engineering. Among the most prominent have been the University of Illinois, Purdue University, Pittsburgh University, and The Pennsylvania State College. Some of these institutions abandoned the course a number of years ago and combined the railway course with the straight course in mechanical engineering, along much the same lines as the average course of study in civil engineering. Pittsburgh University, it is understood, and the Pennsylvania State College are, however, still maintaining a course in railway mechanical engineering. The latter institution, however, is seriously considering the abandonment of this course and including the more important railway subjects in its mechanical-engineering course.

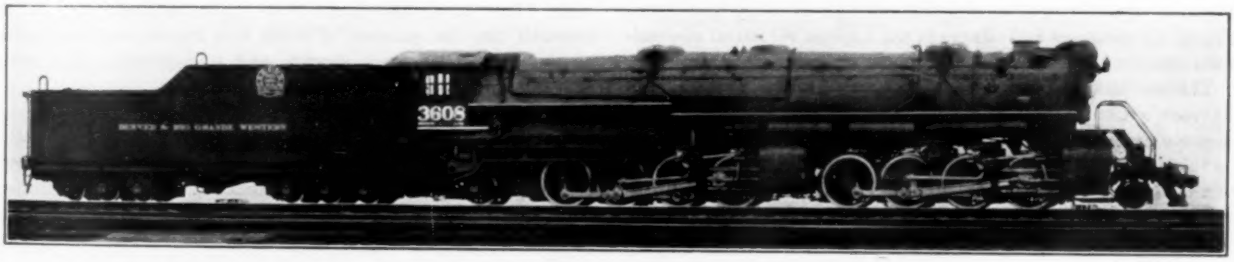
In many respects this trend in railway-mechanical-engineering education will be beneficial from the standpoint of both the railroad and railway-supply industries. It is generally felt that mechanical engineers should have as broad an education as possible, and that specialization in college is not beneficial. It is also felt that a considerable improvement can yet be had in the educational field by a more careful selection of students



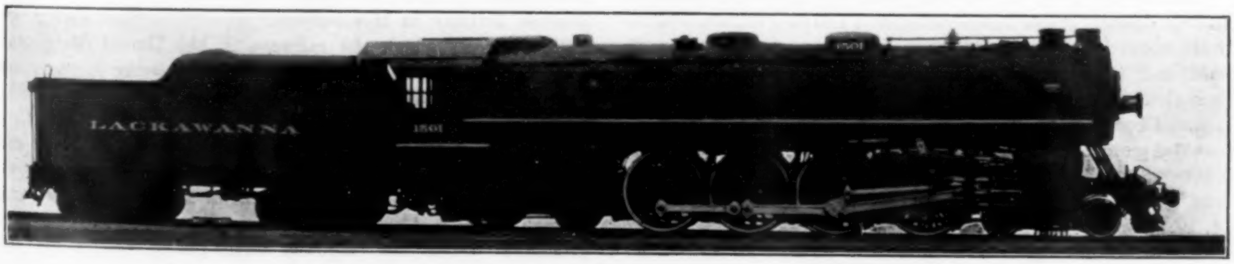

2-8-4 Locomotive Built for the Erie, and Equipped with Booster



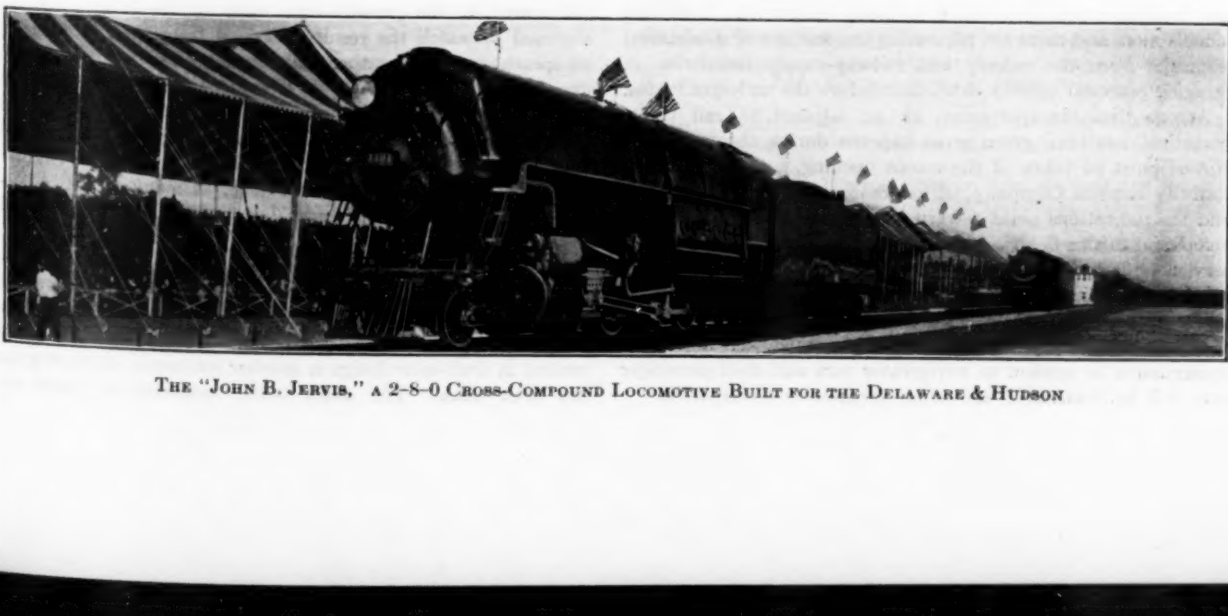

New York Central Locomotive of the Hudson Type (4-6-4)




2-8-8-2 Locomotive Built for the Denver & Rio Grande Western




4-8-4 Locomotive Built for the Delaware, Lackawanna & Western



The "John B. Jervis," a 2-8-0 Cross-Compound Locomotive Built for the Delaware & Hudson

in mechanical engineering, the installation of some scheme of vocational guidance, and the planning of the course of study to more adequately serve the mechanical engineer in railroad work dealing with steam turbines, gas engines, electric traction, etc.

The outstanding development in this field of education, from the standpoint of the railroad and railway industries, is the cooperative plan in engineering and commerce instituted several years ago by the Georgia School of Technology. The original plan of cooperative education for engineers was first instituted in September, 1920, when the textile department of that institution arranged a course, to cooperate with the cotton mills, in the education of textile engineers. Since that time the cooperative plan has been extended to a number of railroads; viz., the Central of Georgia, the Tennessee Coal, Iron & Railway Co., the Georgia Railway & Power Co., the Atlanta, Birmingham & Coast, and the Nashville, Chattanooga & St. Louis. Under the cooperative plan the student spends alternately four weeks in college and four weeks in mechanical-engineering work in the railroad shops at Atlanta, Ga., and the cities within a radius of about 300 miles. By this arrangement the Georgia School of Technology has available two courses in mechanical engineering: viz., the standard four-year theoretical course as given by other engineering colleges, and a five-year course for those students who wish to combine practical experience with technical theory. The cooperative course is under the administration of a director, an assistant, and an advisory board consisting of executives and officers of the various industrial and railroad companies with which the school cooperates.

The research work that is being carried on by the Railroad Division's Committee on Professional Service shows that the opportunities afforded in the railroad industry are comparable to those afforded in any other industry. In all probability there will be a larger number of mechanical engineers entering railroad work in the future. It is believed that an institution offering courses in mechanical engineering could offer a better-balanced course if the design and operation of motive power and rolling stock were included in the mechanical-engineering curriculum.

Considerable progress has been made by the Sub-Committee on Professional Service in collecting facts and information relative to the opportunities afforded the mechanical engineer in the railroad and railway-supply industries. A progress report was presented at the annual meeting in December, 1926, which included considerable data collected up to that time. That report was published in full in February, 1927, issue of MECHANICAL ENGINEERING. A second report will be presented at the Student Branch Meeting of the Metropolitan Section on March 14, 1928.

### Trend in Development

Closer cooperation between technical schools, the railroads, and railway-supply companies is being evidenced. Technical schools more and more are requesting the services of mechanical engineers from the railway and railway-supply industries in bringing practical outside viewpoints before the undergraduates.

Aeronautical transportation, as an adjunct to rail transportation, has been given great impetus during the past year. Notice must be taken of the recent opening, by the American Railway Express Company, of its transcontinental air service, and the indications point toward an even more pronounced development in this field. Aerial transport coordinated with train service under railway-company operation, as well as by independent companies, may confidently be looked for within a relatively short time.

Research and development work in insulation and heat transmission as applied to refrigerator cars and steel passenger cars will be continued, and rapid progress is anticipated.

Iceless refrigeration has been already developed to a point where its advantages in the railway field have been demonstrated, and its extensive use appears to be forecast.

Motor-truck and bus service has been extended. Particular attention is being given to determining conditions under which further extension, from the standpoint of economy and advantageous coordination with steam service, may be made. Mention must also be made of the increase in "auto-bus tours" as an adjunct to passenger travel. In this field the Atchison, Topeka & Santa Fe and the Southern Pacific are the best known. The indications are that there will be considerable increase in such auxiliary services.

The development of the Diesel-electric power units, suitable for rail motor cars, with a weight of engine and generator of not over 26 lb. per hp. has been brought to the Committee's attention. Light-weight units of this character and of a size and flexibility suitable for rail-motor-car use offer encouragement to the further adaptation of this equipment in the not-far-distant future.

Diesel-electric locomotives, arranged for multiple-unit control and suitable for road service, are under construction for the New York Central Railroad. The Ingersoll-Rand Company, the McIntosh & Seymour Corporation, and the General Electric Company are developing and perfecting this method of control.

The American Railway Association's draft-gear tests at Purdue University were started with encouraging results during the year. The same association has made progress also in its research into the question of truck side frames, and the results of this important work should, and undoubtedly will, prove of great benefit to the railroad industry.

Some attention has also been given toward applying mechanical draft to locomotives by using turbine-driven fans for forcing air below the grates. The question of the use of pulverized fuel also has received further attention. Definite reports as to the amount of progress which has been made along these lines have not been available.

Efficiency in the use of fuel, particularly as affecting the smoke-abatement problem, has been actively pursued and considerable progress reported. St. Louis is the center of the greatest activity in this subject.

The interest which the railways in the United States and Canada have in the application of roller-bearing journals has shown a marked increase within the last 12 or 14 months, particularly since the American Railway Association's Atlantic City Convention of June, 1926, at which time exhibits of trucks and other equipment thus fitted attracted no small amount of attention. Prior to this time several railways had been operating a small number of test cars. Within the last 18 months, four prominent trunk-line railroads have placed orders for 480 roller-bearing-equipped passenger cars of all types, all of which are now in service. The largest single order yet placed was for 133 cars. At the present time most of the other roads are disposed to watch the results obtained from the roller-bearing equipment in service rather than to proceed with any wholesale experimenting themselves. It is evident, however, that within the next year or two the manufacturers and the railroads will be possessed of useful data on the operating conditions of this type of bearing, as well as upon the relative merits of competitive types. Particularly is the latter true, as many of the operating advantages have already been well defined by actual tests.

The increase in size of motive power, the length of trains and the larger-capacity cars now in use have brought about modification and improvement in draft gears which provide for the more severe service conditions. The problem of slack control in draft-gear design is another subject in which progress has been made. The much better condition in which air-

brake apparatus is now maintained by the railroads is to be noted. Research in the air-brake field has been continuous and has resulted in the bringing out of a new type of feed valve having greater stability, reliability, and capacity, and a reduced cost in operation and maintenance. There have also been developments in brake-cylinder pressure-retaining valves and in the methods for more uniform application and release of brakes in passenger trains. The increasing use of higher steam pressures and higher steam temperatures has influenced development in air compressors and governors.

The increasing length of passenger trains has been appreciated by the manufacturers of train-heating equipment, and the past year has seen the application of train-heating equipment giving greater assurance that the rear cars of these long trains would be adequately heated. In this development, progress has been made in adapting modifications to the requirements of interchangeability between cars thus equipped and others.

The probable trend of development in the railway field within the next few years will be in the direction of enabling the railways to obtain a greater net income than has been the case during the last ten years. This increase in net income is necessary if the railway plant is to be enlarged so that it may, promptly and effectively, perform the work which it will be called upon to do, and, also to enable it to operate at a cost that its patrons can afford to pay.

### Bibliography

The appended bibliography, while not complete, is nevertheless believed to contain references to published information on most of the subjects covered in the Committee's report. It contains references to articles that have been suggested to the Committee by the various railroads and representatives of other industries which have favored the Committee with information, and appreciation of this cooperation is hereby acknowledged.

H. B. Oatley, *Chairman*.

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# The Mechanical Engineer in the Railroad and Railroad-Supply Industries

IT IS THE belief of the Railroad Division's Sub-Committee on Professional Service that the opportunities afforded the mechanical engineer in the railroad and railroad-supply industries are equal to those afforded in any industry. This belief is based on several facts which are later discussed in this report, probably the most significant of which is that competition with other college-trained men is not as great as is the case in many other industries. A study of the careers of 150 railway officers holding positions from president down to master mechanic, shows that only 43.7 per cent are college graduates. The railroad-supply industry, however, presents a slightly different ratio, 63.6 per cent being college graduates out of a total of 113 railway-supply-company officers ranging from president down to sales representative. In both cases the officers were selected at random with the primary object of obtaining as accurate a picture as possible of the competition to be expected by the mechanical engineer in both industries.

These figures are also significant of one other important factor pertaining to the success of the individual in railroad and railroad-supply work. Knowledge of railroading, individual adaptability, practical experience, and a willingness to work appear to have considerably more value in the mind of the average executive than college education.

It is not the general practice of the railroads to extend preferential consideration to college graduates. It is expected that the college graduate will start on an equal footing with the non-college man and show his worth in actual service. In other words, the college man is worth comparatively little to a railroad company until he has had considerable practical training and experience. This, in the main, is also true of most industries employing technical graduates.

This situation is well described by Robert E. Woodruff in the foreword of his book "The Making of a Railroad Officer."[1]

> To most men, railroad history and stories are fascinating because they are filled with action and achievement. Lives of railroad men are romantic, treating as they do of the hardships of their rough outdoor life. Railroad men are as a whole active, resourceful, enthusiastic. They play the game because they love it. Thousands enter the service each year. Some cannot stand the pace and seek easier jobs in other lines. All begin at the bottom in some capacity or other—there is no royal road to the top.
>
> Some advance, some slowly, but surely—others stagnate and are sidetracked. When questioned, most men are ambitious for achievement, though many are ignorant of how to accomplish it or of where to get the necessary knowledge. Some do not realize they must fit themselves for larger responsibilities before they can be seriously considered for promotion.

Incidentally, Mr. Woodruff starts his future railroad officer as a section laborer.

### How to Use the Information Contained in This Report

Much of the information contained in this report was obtained by studying and analyzing the careers of railroad and railroad-supply officers, published in the railway trade press. This was also supplemented by writing direct to the various companies for additional information. The Sub-Committee on Professional Service has assumed from the beginning of its work on this project that what the young mechanical engineer wants and should have are facts, not advice. He ought to have a fairly accurate picture of the industry he expects to work in before he enters it. Such a picture is not difficult to obtain if one takes the time to assemble and study the facts. A study of the careers of railroad and railroad-supply officers has been made in preparing this report, and it will reveal many essential facts. Additional information can also be obtained from those who are now engaged in railroad and railroad-supply work.

Facts obtained from the last source mentioned should, however, be given careful consideration. To have won success in one's chosen profession does not always qualify one to fill the role of adviser in the selection of another's life work. He may, in fact, be disqualified by that very circumstance. On the other hand, a man who has spent the best years of his life near the bottom of the ladder is likely to paint a pessimistic picture of the opportunities to be found in railroad work. Still, a good business man makes his banker his friend and counselor. Likewise, the young railroad man should make it his business to cultivate friends and advisers among the older railway officers.[2]

Study of the facts and information contained in this report should be supplemented by consultation with railroad and railway-supply-company officers, and with members of the mechanical-engineering faculty of the institution the student is attending. The burden, however, of making the final decision should rest with the young mechanical engineer himself.

It must also be appreciated that opportunity in a certain industry is very closely allied to the progress that is being made in the way of developments within the field itself. The young mechanical engineer should study the report of the Sub-Committee on Professional Service in conjunction with the report of progress in the industry which is presented by the Railroad Division each year at the Annual Meeting of the Society. Also, the *Railway Age* publishes a special issue, the first number of the year, known as the Annual Statistical Number, which contains a comprehensive review of developments and accomplishments in the industry during the preceding year.

### Question of Knowing One's Own Ability

It is essential that the young mechanical engineer know his own characteristics and ability. In finding these out, he can obtain considerable assistance from his friends and faculty advisers. The graduate from an engineering school who anticipates a railroad career should carefully consider two questions, namely, "Do I want to use my engineering education as a basis for a purely engineering career, or do I want to use it, together with a supplementary business education, as a means of eventually reaching an executive position?"[3]

The man who would follow the first course and who is interested in engineering work for the work itself, or in new design and construction, is sure to suffer somewhat of a disappointment in railroad service. Unfortunately, relatively little of the work

[1] "The Making of a Railroad Officer," by Robert E. Woodruff, General Manager, Eastern District, Erie R.R. Published by the Simmons-Boardman Publishing Company, New York.

[2] See "What Opportunities Are Afforded the Technical Graduate in Railroad Work," by Marion B. Richardson, beginning on page 13 of the March, 1926, issue of *The Penn State Engineer*.

[3] See the *Railway Age*, June 12, 1926.

performed by the average railroad mechanical-engineering office is of a nature that will keep a talented designing engineer continuously occupied with new and interesting problems. The development of the railroad-supply industry has had an important effect in placing the larger part of the design work in the mechanical-engineering department of the manufacturer. In all probability the man following the first course will find greater opportunity in the supply industry.

If the college man entering railroad service is the type who wishes to use his engineering education as a means of possibly reaching an executive position, either in or above the engineering department, then there is one thing that cannot be overlooked—as he advances he gradually becomes more of a business man and less of an engineer. If he has failed to educate himself in the principles of business, the chances for becoming an executive are not great. The railroad executive whose duties may demand an engineering knowledge are such that a relatively small portion of the things which he must know involve a detailed knowledge of engineering principles as compared with the principles of business administration.

The mechanical department of a railroad is but a part of an immense business organization which, like any other business, is operated to make money. Unfortunately, the mechanical department is in a position principally to spend money and save money; as a consequence, the labors of the members of that department are often looked upon as "non-productive." If a college man intends to enter railroad service and be satisfied with what he can learn in any one office or department, he will make no greater progress on the railroad than if he pursued the same tactics in any other industrial organization. The big thing is to know enough about the job ahead to be able to step into it when the opportunity offers, and this calls for self-education in the principles of business.

Unfortunately, a railroad cannot be run on paper. Operations may be carefully planned beforehand, but conditions over which no one has any control may make it necessary to alter these plans at the last moment. Therefore, any college man in railroad service who fails to get as much as possible of the practical side of railroading is doomed to make little progress in railroad work. Any man who has spent four years in college learning how to think for himself certainly should not be at a loss for ways and means to get all he wants on a railroad.

The Railroad Division's Sub-Committee on Professional Service does not believe that to confer a distinctive title upon a college man in railroad service would materially better his situation. In fact, some consider such titles a considerable handicap. "Titles can be created with the flourish of a pen and wiped out with a bad breakfast." Some of the real jobs on any railroad are those which carry unimposing titles, and, on the other hand, some jobs with magnificent titles leave much to be desired on pay day. Every man who has had practical railroad experience realizes that it is desirable to emphasize his education as little as possible. What the young mechanical engineer should do, in railroad work or elsewhere, is to lose his identity as a college man as quickly as possible.

## Two Reasons Why Advancement Is Apt to Be Slow

There are two principal reasons why advancement in railroad work may be slow. First, because the business as a whole is so complicated and departmentalized that it takes years of actual work to become acquainted, even in a general way, with many phases of it. This is in contrast with any line of business that consists mostly of one or two operations, such as buying and selling, or the manufacture and sale of a limited variety of articles, the whole plant being in one place. In any such line, one with reasonable aptitude and liking for the work can much more quickly master its details and be in position to advance more rapidly than would be likely in a more complicated and departmentalized business.

The second reason is that the railroads have long since come to a stage of routine as contrasted with immediate and rapid growth. They are organized to handle their business from day to day, but are not expanding in any such manner as to call for a steady and large supply of trained men to fill newly created responsible positions. A man who may be very capable is apt to find himself in a situation similar to a bucket in a bucket brigade: that is, he passes along just as fast as those who happen to be ahead of him travel. This is an unavoidable condition in any organization that has attained its growth.

The second reason, however, is subject to a number of modifications. The railroad industry has been going through a number of important developments in recent years with respect to its employees that cannot help but effect an improvement in the status of the mechanical-engineering graduate. Many railroad companies are utilizing the facilities afforded by various state university-extension departments, vocational educational bureaus, correspondence schools, and other educational organizations for the training of foremen and supervisors. The requirements for the enrolment of regular apprentices are becoming more strict. Some railroads are now requiring a high-school education or the equivalent before a man can enroll as a regular apprentice. Many of the larger railroads are sponsoring such activities as the American Railway Boys' Clubs, the educational features of the Railroad Y.M.C.A., Younger Railroad Men's Conferences, etc., in an effort to raise the standards of supervision. Of course, this means more competition for the college graduate. But it also means more adequate appreciation and utilization of college training by the railroad executives.[4]

## Comparison of the Railroad with Other Industries

There are approximately 1000 railroads in the United States and Canada, about 176 of which are Class I railroads (railroads having an operating income above $1,000,000). The Class I railroads operate approximately 90 per cent of the total railway mileage in the United States and earn about 96 per cent of the total revenues. According to the November, 1927, Monthly Labor Review, published by the U. S. Bureau of Labor Statistics, there were employed on these roads in August, 1927, a total of 1,796,194 men and women. A comparison of this figure with the number employed by other industries during the same period is given in Table 1. The second largest industry, according to the number employed, is the iron and steel industry, the textile industry being third.

TABLE 1 COMPARISON OF EMPLOYMENT IN 13 GENERAL GROUPS OF INDUSTRIES DURING AUGUST, 1927

| | Number of establishments | Average number of wage earners |
|---|---|---|
| Railroads | Total Class I* | 1,796,194 |
| Iron and steel and their products | 1806 | 648,701 |
| Textiles and their products | 1885 | 602,623 |
| Vehicles for land transportation | 1194 | 479,826 |
| Car building and repairing, steam railroads | 559 | 138,381 |
| Miscellaneous industries | 413 | 251,850 |
| Food and kindred products | 1656 | 223,457 |
| Lumber and its products | 1156 | 219,669 |
| Paper and printing | 910 | 172,365 |
| Leather and its products | 360 | 128,564 |
| Stone, clay, and glass products | 638 | 109,776 |
| Chemicals and allied products | 362 | 88,679 |
| Metal and metal products, other than iron and steel | 228 | 51,595 |
| Tobacco products | 173 | 39,670 |

* Includes 172 Class I railroads, 15 switching and terminal roads of this class and 24 small roads included in system reports.

[4] Personnel Management on the Railroads, A Study by the Metropolitan Life Insurance Company. Published by the Simmons-Boardman Publishing Company, New York.

Figures showing the proportion of technical graduates—for our purposes, mechanical engineers—to the total number employed would be of value in this table. The Sub-Committee has not, however, found any source from which such information could be obtained. A general idea of the number of supervisory positions in which mechanical-engineering training would be of service is shown in Table 2. Care should be shown, however, in the use of the total figure, due to the fact that many of the executive and staff officers fill positions requiring legal, medical, or business training. Furthermore, this total does not include special apprentices. The division officers and assistants include men in all departments. The larger proportion of the architectural and engineering assistants are in all probability men of civil- or mechanical-engineering training. Special apprentices are usually made inspectors upon completion of their course.

TABLE 2 NUMBER OF EMPLOYEES HOLDING POSITIONS WHERE MECHANICAL ENGINEERING TRAINING WOULD BE OF SERVICE, AUGUST, 1927, ON CLASS I RAILROADS IN THE UNITED STATES*

| | |
|---|---|
| Executive, general officers and assistants | 7,551 |
| Division officers, assistants and staff assistants | 9,503 |
| Architectural, chemical and engineering assistants | 7,685 |
| Sub-professional engineering and laboratory assistants | 4,232 |
| General foremen, M. of E. | 1,440 |
| Assistant general foremen and department foremen, M. of E. | 11,129 |
| Equipment, shop and electrical inspectors | 1,585 |
| Material and supplies inspectors | 1,913 |
| Gang foremen and gang leaders, M. of E. | 11,036 |
| | 56,074 |

* Wage statistics report, Interstate Commerce Commission, for August, 1927.

A comparison of the total number employed with the total number of officers shows quite clearly that the principal job of the majority of mechanical-department officers pertains more to handling and leading men than to strictly mechanical-engineering work. To illustrate, the superintendent of the car department of one of the smaller Class I railroads in the East has an average of 1200 men under his jurisdiction working at different points on the system. As a further illustration, there are employed by the railroads in the maintenance of equipment about 484,000 men. As a comparison, there are about 1400 general foremen and 11,000 assistant general foremen and department foremen employed by the Class I railroads in the mechanical department. The general foremen are therefore captains of an immense army. Their work may be roughly divided into two parts: first, that of contributing to improvements in shops, shop methods, and shop machinery, and secondly, that of supervising and training employees and improving their morale.

This, in brief, is a summary of the experience and training the college graduate must have to fill higher positions. Finally, the young mechanical engineer must know and appreciate the fact that the railroad industry is subject to regulation by the Government.[5] As a rule, government agencies are slow to move and are likely to hinder the development of an industry unless they are able to keep in step with the times. The rules and regulations laid down by the Interstate Commerce Commission affect the work of all departments of a railroad, and it is necessary that the railroad officer know just how these regulations relate to the work of his department.[6] The railway-supply-company officer must also be sufficiently familiar with the rules and regulations of the Interstate Commerce Commission to meet its requirements in the materials that his company manufactures. Government regulation, however, has its good features as well as its bad, and fortunately the policy of the various bureaus of the Interstate Commerce Commission is one of helpfulness rather than hindrance. In addition, the American Railway Association, of which practically all the railroads are members, makes certain rules and sets up standards with which the mechanical-department officers of the railroad and the railway-supply-company officers, must be familiar. Summarizing, training in the utilization of statistics and reports is a necessary qualification to the mechanical engineer in both the railroad and railroad-supply industries.[7]

### The Railway Organization

In order to understand the part that the mechanical department plays in a railway organization, a brief outline should be given. The organization of a railway company divides itself naturally into several main departments which have clear lines of demarcation. These departments are the legal, the traffic, the treasury, the accounting and auditing, the operating, and the maintenance.

Men of mechanical-engineering education are in demand for service in the maintenance and operating departments. The importance of mechanical-engineering training with respect to the work performed is greatest in the maintenance-of-equipment department. The work of the traffic department can be compared to that of the sales department of a manufacturing concern, and in fact it actually does sell the services of the railroad to the shipper and traveler.

The operating department mans and moves the trains, operates the yards, and mans the stations. It is generally considered to be the most important department. Excluding those who started their railroad career in the executive department as secretary to an executive officer or as chief clerk, it is the operating department that supplies the president on most railroads. This fact was evident when collecting the data for Table 3. The figures shown in the left-hand column will not total 79, due to the fact that the majority worked in several departments before becoming president. In other words, 63 of the 79 worked in the executive, financial, or legal department, four in the accounting, etc.

The good operating man seldom finds it desirable to leave railway service to work in any other industry. When he does, it is to take a position where the executive qualities of leadership bring him greater reward.

TABLE 3 CAREERS OF THE PRESIDENTS OF 79 CLASS I RAILROADS

| | Total | Common school | High school or equiv. | College graduate | College graduates, per cent |
|---|---|---|---|---|---|
| Education | 79 | 33 | 12 | 34 | 43 |
| Department in which trained: | | | | | |
| Executive, financial, legal | 63 | 29 | 6 | 28 | 44.4 |
| Accounting | 4 | 3 | 1 | 0 | 0 |
| Traffic and claims | 13 | 8 | 4 | 1 | 7.7 |
| Operating and telegraph | 42 | 22 | 9 | 11 | 26 |
| Purchasing | 5 | 2 | 2 | 1 | 20 |
| Mechanical | 3 | 2 | 0 | 1 | 33 |
| Engineering, bridges, and signals | 25 | 9 | 2 | 14 | 56 |

As shown in Table 3, the engineering or maintenance-of-way department is another that has always seemed to have received proper recognition. Many railroad division engineers or chief engineers have succeeded in stepping over into the operating department and thus proceeded on their way to the top. The list of railway presidents who started in railway service as rodmen or transitmen is quite a long one. This information is of interest to the mechanical engineer, whose technical education is similar in many respects to that of the civil engineer.

[5] "The Interstate Commerce Commission, Its History, Activities, and Organization," by Joshua Bernhardt. The Johns Hopkins Press, Baltimore, Md.

[6] "The Regulation of the Railways," by Samuel O. Dunn. Published by D. Appleton and Company, New York.

[7] "Economics of Railway Operation," by M. L. Byers, Chairman, Valuation Committee, Seaboard Air Line. Published by McGraw-Hill Book Company, New York.

### The Mechanical Department

Generally speaking, the mechanical department is usually subordinated to the transportation department. It seems to lack a class consciousness and in this respect is quite different from the engineering department. The mechanical department is in charge of the design of cars and locomotives, and of their maintenance in good order. No less than 25 per cent of all railway operating expenses and from one-half to two-thirds of the expenditures for capital improvements come under the jurisdiction of this department. This shows that the job of the mechanical-department officer is one of importance and great responsibilities and requires a man capable of exercising mature judgment.

This statement is undoubtedly emphasized by the figures given in Table 4, which shows the years required for mechanical engineers to reach certain positions in the mechanical department of a railroad. One mechanical engineer worked for 49 years before becoming head of the mechanical department of his road. Another worked for 10 years. The average time required for all those of whom the Sub-Committee obtained complete data was 22.8 years.

TABLE 4 YEARS REQUIRED FOR MECHANICAL ENGINEERS TO REACH CERTAIN POSITIONS IN THE MECHANICAL DEPARTMENT OF A RAILROAD

| | Longest time | Shortest time | Average |
|---|---|---|---|
| General supt. of motive power or head of mechanical department | 49 | 10 | 22.8 |
| Assistant or division supt. of motive power | 36 | 7 | 18.8 |
| Mechanical engineer | 33 | 4 | 15.2 |
| Assistant mechanical engineer | 11 | 4 | 8 |
| Engineer of tests | 19 | 5 | 9.75 |
| Engineer of motive power | 24 | 7 | 18 |

Table 5, which shows the number of years that have been required for mechanical engineers to reach certain railroad executive positions, cannot be considered as indicative of the actual opportunities afforded members of the profession in reaching the positions mentioned. Changing conditions in the railroad industry will, in all probability, see more mechanical engineers as railroad presidents. This is perhaps illustrated by the fact that there are now six vice-presidents who have come up from the mechanical department. The office of chief purchasing officer is also included in this table on account of the fact that some railroad managements consider technical training to be a necessary requirement for the duties of this position. At the present time three mechanical engineers are serving as chief purchasing officers.

TABLE 5 YEARS REQUIRED FOR MECHANICAL ENGINEERS TO REACH CERTAIN RAILROAD EXECUTIVE POSITIONS VIA THE MECHANICAL DEPARTMENT

| | Number of officers | Longest time | Shortest time | Average |
|---|---|---|---|---|
| President | 1 | 38 | .. | 38 |
| Vice-president | 6 | 40 | 11 | 30.3 |
| Chief purchasing officers | 3 | 35 | 26 | 32.1 |

### Interests of Railroads and the Railroad-Supply Industry Closely Interwoven

The interests of the railroads and the railroad-supply industry are so intimately interwoven that it is impossible to separate them. The railroads are interested in furnishing that standard of transportation which will best meet the public requirements. They are specialists in transportation, and that in itself is no mean task. They are large purchasers of material and supplies, which is indicated by the fact that for several years—since and including 1920—the Class I railroads have expended in excess of a billion dollars a year, chargeable to the operating account for materials and supplies, exclusive of fuel for locomotives.

The railway-supply manufacturers, specializing on the development, production, and sale of equipment and supplies and enjoying plenty of competition, have made a remarkable contribution to the railroads and the public served by them. The supply manufacturer must keep in intimate contact with the railway operating problems and practices. He frequently goes to the railroads for men for important places in his organization, and relieves the railroad organizations of production details which they are not in a position to handle.

### Facts Relative to the Railroad-Supply Industry

Over 40 per cent of the executive and technical officers and sales staffs of railway-supply concerns, promoted since December, 1919, have either started or worked some time in their careers for a railroad. Approximately 500 manufacturing companies engaged in selling supplies to the railroads, wholly or in part, are listed in the Pocket List of Railroad Officials. Table 6 shows the number of companies engaged in manufacturing and selling certain classes of material, the railroad department responsible for selecting each class of material and its utilization, and the department from which men are usually recruited by the supply companies. These supply companies employ approximately 7000 men as executives and sales engineers, a large proportion of whom the Sub-Committee has good reason to believe are men of technical education. There are also about 40 private-car companies which own and operate over 1000 cars which should also have need for a limited number of mechanical engineers. Five trade magazines published to serve the interests of the railroad industry employ a limited number of mechanical engineers on their editorial and business staffs. These publications, however, employ only mechanical engineers who have had considerable railroad experience.

TABLE 6 CLASSIFICATION OF APPROXIMATELY 500 RAILWAY-SUPPLY COMPANIES ACCORDING TO PRODUCT

| Material sold to railroads | Number of companies | Railway department concerned | Railway department from which men are usually recruited |
|---|---|---|---|
| Air-brake equipment and supplies | 11 | Mechanical<br>Operating | Mechanical<br>Operating |
| Car builders | 24 | Traffic<br>Mechanical | Mechanical |
| Car equipment and appliances | 148 | Mechanical<br>Operating | Mechanical |
| Electric-railway equipment | 25 | Mechanical<br>Electrical | Electrical |
| Electric-shop equipment | 16 | Mechanical<br>Electrical | Electrical |
| Engineering construction | 49 | Engineering | Engineering |
| Forgings for railway use | 5 | Mechanical<br>Engineering | Mechanical<br>Engineering |
| Locomotive builders | 5 | Operating<br>Mechanical<br>Engineering | Mechanical |
| Locomotive appliances | 26 | Mechanical<br>Operating | Mechanical |
| Lumber for railway use | 3 | Engineering<br>Mechanical | Engineering<br>Mechanical |
| Machine and small tool manufactures | 39 | Mechanical | Mechanical |
| Shop equipment | 82 | Mechanical | Mechanical |
| Miscellaneous | 28 | All depts. | All depts. |
| Power-plant equipment | 8 | Electrical<br>Mechanical | Electrical<br>Mechanical |
| Rails and track supplies | 89 | Engineering | Engineering |
| Railway castings | 29 | Mechanical | Mechanical |
| Signal equipment and supplies | 42 | Signal<br>Electrical<br>Engineering | Signal<br>Electrical<br>Engineering |
| Water supply and treating | 12 | Engineering<br>Mechanical | Engineering |
| Dealers in used railway supplies | 7 | Engineering<br>Mechanical | Engineering<br>Mechanical |
| Rail motor car builders | 3 | Operating<br>Mechanical | Operating<br>Mechanical |

### How the College Man Can Gain Promotion

If the mechanical engineer starts at the bottom of the ladder on graduation from college, he can expect to follow one of five general routes for both the railroad and railroad-supply industries inclusive. Referring to Fig. 1, these general routes are lettered consecutively from *A* to *F*. These routes were charted from

replies to question (*h*)[8] in the questionnaires sent to a selected list of railroad and railway-supply companies, and from an analysis of the careers of various railroad and railroad-supply officers. The dotted lines show some of the transfers which have actually been made by men between the two allied industries. In this connection, it is well to keep in mind that the men who have transferred from railroad to railway-supply companies, and vice versa, have been able to do so on the experience or record attained in either one of the two industries. In other words, the essential experience and requirements for both the railroad and railroad-supply industries are, from all practical standpoints, basically the same.

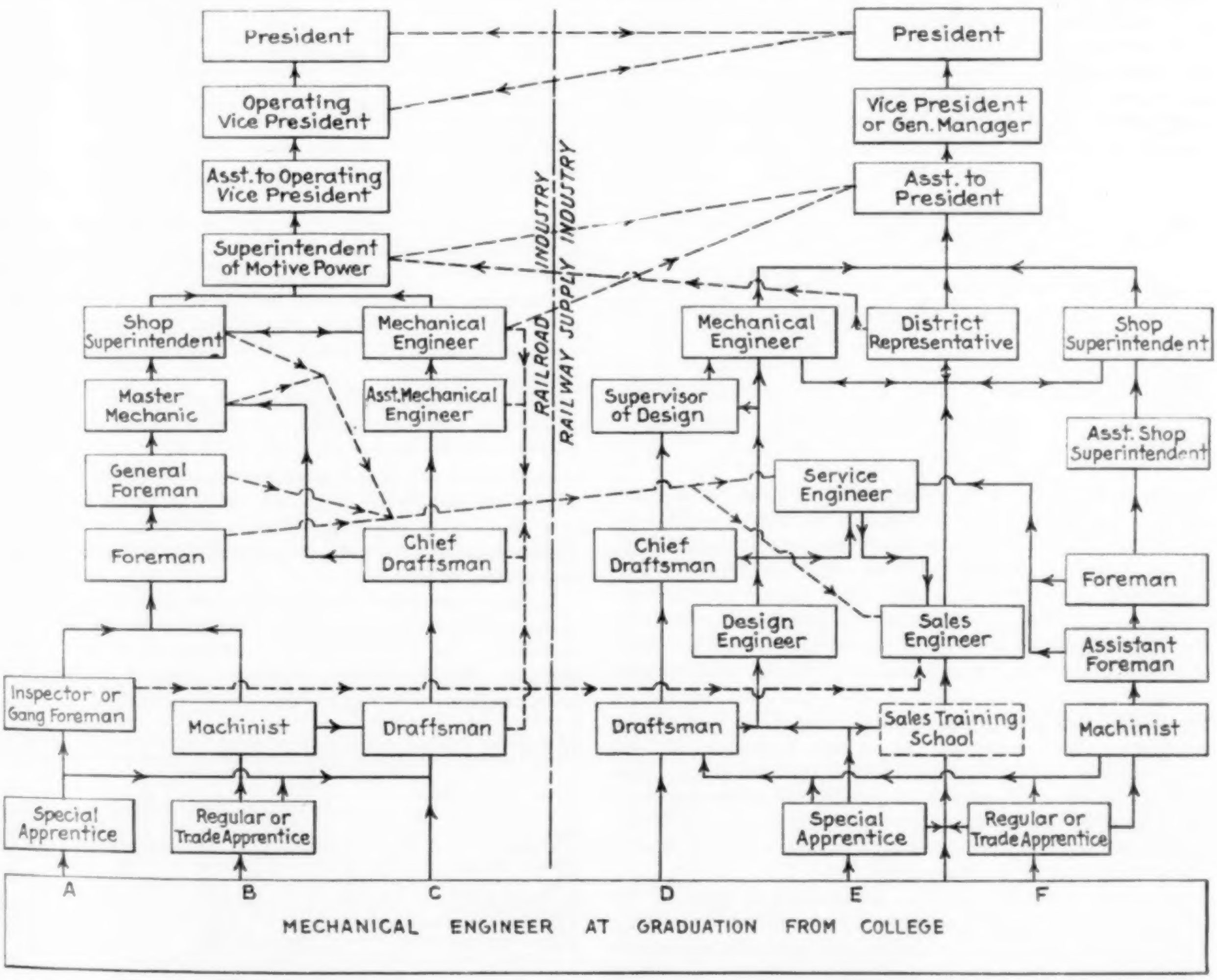


FIG. 1 CHART SHOWING THE GENERAL RATES OF PROMOTION USUALLY FOLLOWED IN THE RAILROAD AND RAILROAD-SUPPLY INDUSTRIES

The Sub-Committee on Professional Service does not wish to convey the impression that each man must necessarily follow one of the five general routes shown in Fig. 1 to get to the top. Analysis of the careers of railroad and railroad-supply officers shows that some have jumped from one route to another or skipped one or more positions in the usual direct line of promotion. There have been instances where special apprentices have become machinists, and there have also been instances of promotion to foremen on the completion of the special apprentice course. It depends on the characteristics and ability of the individual whether he moves slowly or rapidly to higher positions of responsibility.

### Seniority Rules Delay Promotion

The seniority rules are generally admitted to slacken the rate of promotion for the college man in railroad work, but present no insurmountable barrier if superior capacity is demonstrated. The prime necessity of not impairing morale among the employees by anything savoring of favoritism is stressed very generally, although seniority, it is said, will give way to demonstrated superior capacity to fill a higher post. In other words, the burden of proof, "the risk of non-persuasion," must be arrived at by the college man who aspires to promotion in competition with the man of longer service.[9]

Among the facts the young mechanical engineer would like to know before entering the employ of any company are those relating to the manner in which promotion is gained. In other words, must he play politics? be a relative of some high officer, either through birth or marriage? or is promotion gained solely

[8] See the progress report of the Railroad Division's Sub-Committee on Professional Service in the February, 1927, issue of *Mechanical Engineering.*

[9] See abstract of paper by Winthrop M. Daniels, Yale University, read at the annual meeting of the American Economic Association, Chicago, December 30, 1924. February 7, 1925, *Railway Age,* page 375.

through merit? Naturally such information is practically impossible to obtain until one has been in the employ of the company for a time and has had an opportunity to discover some of the inside workings. Fortunately, the majority of the Class I railroads have such large organizations that family influence and politics do not have much weight in obtaining promotion. In fact, a careful check of various records and statistics of the ownership and official personnel of the railroads shows that "family controlled" companies are few in number and are practically all small roads.

Analysis of the careers of officers in both the railroad and railway supply industries shows that the college graduate has a distinct advantage over the non-college man. Reference is made to Tables 7 to 9, inclusive. Table 7 shows the results of a study made of the railroad careers of 25 railroad officers in six different grades. The right-hand column of the table shows the number of years gained by the college graduate in reaching each position listed over the time required by the non-college man in reaching the same position. The officers, selected at random, are all employed by Class I railroads.

TABLE 7 AVERAGE AGES OF 25 RAILROAD OFFICERS IN EACH GRADE SHOWN, TIME REQUIRED TO REACH CERTAIN POSITIONS, AND TIME GAINED BY COLLEGE GRADUATES

| | Average age, years | Average time in R.R. service, years | College trained, per cent | Average time for non-college man, years | Average time for college graduate, years | Time gained by college graduate, years |
|---|---|---|---|---|---|---|
| President | 58.3 | 30 | 53 | 34 | 24 | 10 |
| Vice-president | 50.8 | 28.1 | 48 | 30.7 | 25.2 | 5.5 |
| General manager | 49 | 30.5 | 16.8 | 31.4 | 26.2 | 5.2 |
| Superintendent of motive power | 43.8 | 25.8 | 44 | 29.9 | 19.9 | 10 |
| Mechanical engineer | 35 | 13.75 | 80 | 14.6 | 13.5 | 1.1 |
| Master mechanic | 47.4 | 22.7 | 20 | 24.1 | 15.2 | 9.4 |

In studying this table it is well to keep in mind the fact that the superintendent of motive power is the active head of the mechanical department. A master mechanic is head of the repair shops of a division, and quite often has charge of both locomotive and car repairs. On most roads, however, the master mechanic has only locomotive maintenance to supervise. The mechanical engineer usually reports to the superintendent of motive power, and his work generally pertains to the design, alteration, and selection of rolling stock and shop equipment. Practically all of the mechanical engineers in Table 7 are college graduates. Those who are not college graduates obtained their technical training at night school or by home study. This accounts for the small gain of 1.1 year by the college man over the non-college man. In other words, practically all of the mechanical engineers employed by the railroads have had a college education or its equivalent.

The Sub-Committee felt it to be essential to have all the information contained in this report of as recent date as possible. Table 8 shows the careers of officers holding certain representative positions in railway-supply-manufacturing companies. In collecting data for this table, only the careers of officers promoted since December, 1919, were considered. An interesting item in this table is the large number of vice-presidents as compared with officers of lower rank. The reason for having 37 vice-presidents and only 13 general managers and 11 chief engineers is that the functions of the latter officers are quite often handled by men holding the title of vice-president. It is not an uncommon thing to have a "vice-president in charge of engineering" in a railway-supply company or to see the title of "vice-president and general manager."

Tables 8 and 9 are arranged for comparison with Tables 3 and 7. It is interesting to note the similarity in respect to time element between the careers of railroad presidents and the presidents of railway-supply companies. There is also a large degree of similarity in this respect between the vice-presidents in both industries, but a somewhat greater difference in figures appears in the careers of officers of lower rank. This is due largely to the fact that the growth of the railroad-supply industry is comparatively more recent than that of the railroads. Again the college-trained man appears to have a distinct advantage over the non-college man.

TABLE 8 CAREERS OF OFFICERS HOLDING CERTAIN REPRESENTATIVE POSITIONS IN RAILWAY-SUPPLY COMPANIES

| | No. | No. who started on R.R. | No. who started with R.S. Co. | Education: Common school | Education: High school or equiv. | Education: College grads. | Per cent of college grads. |
|---|---|---|---|---|---|---|---|
| President | 28 | 6 | 22 | 4 | 6 | 18 | 55 |
| Vice-president | 37 | 22 | 15 | 10 | 8 | 19 | 51.4 |
| General manager | 13 | 4 | 9 | 2 | 1 | 10 | 77 |
| Chief engineer | 11 | 4 | 7 | 1 | 1 | 9 | 81.8 |
| Manager of sales | 12 | 7 | 5 | 2 | 3 | 7 | 58.3 |
| Railroad representative | 12 | 9 | 3 | 2 | 1 | 9 | 75 |

TABLE 9 AVERAGE AGES, TIME REQUIRED TO REACH CERTAIN POSITIONS, AND TIME GAINED BY COLLEGE GRADUATES —RAILWAY-SUPPLY COMPANIES

| | Average age, years | Average time in R.R. & R.S. service, years | Average time for non-college man, years | Average time for college graduate, years | Time gained by college graduate, years |
|---|---|---|---|---|---|
| President | 56.6 | 27.1 | 35.5 | 22 | 13.5 |
| Vice-president | 47.75 | 28.9 | 32.2 | 23.8 | 8.4 |
| General manager | 44.7 | 29.2 | 32.4 | 26 | 6.4 |
| Chief engineer | 46.25 | 23.2 | 31 | 20 | 11 |
| Manager of sales | 46 | 21.75 | 27.25 | 18.9 | 8.35 |
| Railroad representative | 43 | 27.1 | 20.9 | 3.8 | 17.1 |

The figures shown in Table 9 do not represent an average for perhaps the four lower grades, but only a limited number as is indicated by the figures shown in Table 8.

Table 10 is arranged for comparison with Table 4. Higher officers are included in Table 10, however, owing to the fact that the duties and responsibilities of many railway-supply-company executives involve problems that are of a mechanical-engineering nature.

It can be said that a large share of the problems confronting the president of the average railway-supply company are similar to those of the superintendent of motive power of a Class I railroad. He should have sufficient technical knowledge to make intelligent decisions on engineering problems.

TABLE 10 YEARS REQUIRED FOR MECHANICAL ENGINEERS TO REACH CERTAIN REPRESENTATIVE POSITIONS IN A RAILWAY-SUPPLY COMPANY

| | Longest time | Shortest time | Average |
|---|---|---|---|
| President | 45 | 15 | 26.8 |
| Vice-president | 39 | 11 | 25.2 |
| General manager | 45 | 12 | 29 |
| Chief engineer | 36 | 20 | 26.4 |
| Assistant engineer | 22 | 15 | 19 |
| Manager of sales | 40 | 12 | 21.2 |
| Assistant or district manager of sales | 26 | 11 | 19.6 |
| Railroad representative | 43 | 4 | 21.2 |

## Salaries Paid in the Two Industries

One of the questions asked in the questionnaire mailed to the various railroad and railway-supply companies in 1927 was: What length of time is required for a man to reach a position paying, say, $5000 a year? Summarizing the replies, it may be said that some railroads do not pay this amount. On those railroads that do pay this sum, the time required would be not less than ten years in the ordinary course of advancement. Again summarizing the replies of the railway-supply companies, no definite length of time can be determined—it will vary with conditions and individuals.

A rough comparison of the salaries paid mechanical engineers in the railroad and railroad-supply industries with the salaries paid engineers in all industries is shown in Figs. 2 to 4, inclusive.

A tabulated analysis of the earnings of engineering graduates in all industries is also shown in Table 11. The data shown in this table and plotted in Fig. 2 were supplied to the Society for the Promotion of Engineering Education by cooperative committees from the faculties of a large number of technical institutions in connection with an investigation made by that society in 1924. The information was obtained by the faculty committees from the alumni of their respective institutions.

TABLE 11 ANALYSIS OF EARNINGS OF ENGINEERING GRADUATES IN ALL INDUSTRIES AS OF JUNE 1, 1924*

| | | | Annual Earnings, in Dollars | | | | |
|---|---|---|---|---|---|---|---|
| Class | Years since graduation | Number reporting | Limit of lowest 25 per cent | Median | Limit of highest 25 per cent | Maximum | Most frequent |
| 1924 | 0 | 1,191 | 1,200 | 1,476 | 1,560 | 4,080 | 1,200 |
| 1923 | 1 | 1,218 | 1,560 | 1,800 | 1,980 | 5,100 | 1,800 |
| 1922 | 2 | 1,023 | 1,800 | 2,100 | 2,400 | 9,000 | 1,800 |
| 1919 | 5 | 309 | 2,400 | 2,860 | 3,500 | 25,000 | 3,000 |
| 1914 | 10 | 498 | 3,110 | 4,000 | 5,100 | 50,000 | 5,000 |
| 1909 | 15 | 430 | 3,600 | 5,000 | 8,000 | 49,500 | 6,000 |
| 1904 | 20 | 238 | 4,000 | 5,500 | 10,000 | 90,000 | 4,000 |
| 1894 | 30 | 116 | 4,500 | 7,500 | 15,000 | 100,000 | 6,000 |
| | Total | 5,023 | | | | | |

* "Study of Engineering Graduates," published by the Society for the Promotion of Engineering Education, p. 287.

TABLE 12 MAXIMUM, MINIMUM, AND AVERAGE ANNUAL SALARIES PAID FOR CERTAIN REPRESENTATIVE POSITIONS OR THEIR EQUIVALENTS IN THE MECHANICAL DEPARTMENT OF A RAILROAD IN 1921

| | Maximum | Minimum | Average |
|---|---|---|---|
| General superintendent of motive power or head of mechanical department | $25,000 | $4,500 | $8,430 |
| Assistant or division superintendent of motive power | 10,200 | 4,000 | 6,660 |
| Mechanical engineer | 11,320 | 4,000 | 5,410 |
| Assistant mechanical engineer | 9,600 | 3,700 | 4,930 |
| Engineer of tests | 10,000 | 4,000 | 5,680 |
| Engineer of motive power | 8,000 | 4,000 | 5,940 |

Table 12 shows the maximum, minimum, and average salaries paid for six representative positions in the mechanical department of a railroad. These data together with the data from which the curves in Fig. 3 were plotted was obtained from a report of hearings before the Committee on Interstate Commerce, United States Senate, in 1921. The median and minimum curves are undoubtedly somewhat higher after five years

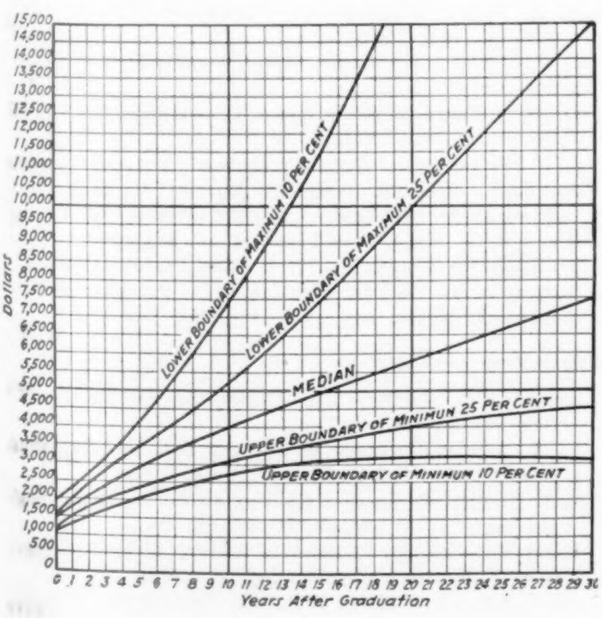


FIG. 2 CHART SHOWING THE EARNINGS OF ENGINEERS IN ALL INDUSTRIES BY YEARS AFTER THEIR GRADUATION FROM UNIVERSITIES AND COLLEGES

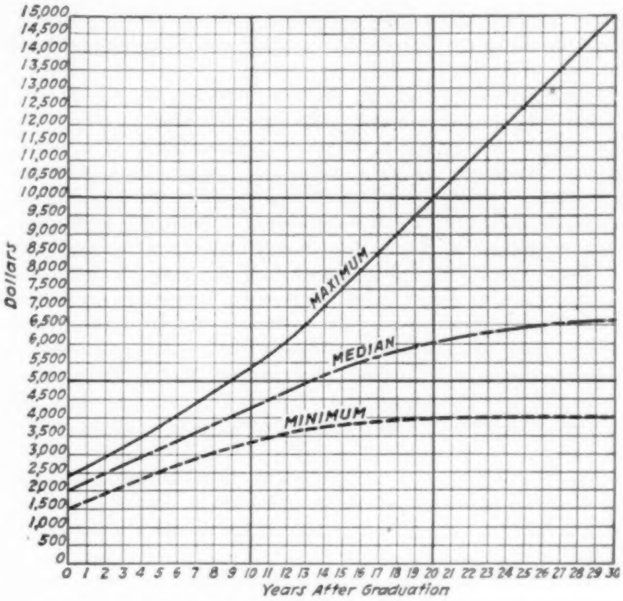


FIG. 3 CHART SHOWING THE EARNINGS OF MECHANICAL ENGINEERS EMPLOYED BY RAILROADS UP TO AND INCLUDING THE POSITION OF CHIEF OF MOTIVE POWER

out of college than they should be, due to the fact that complete data pertaining to salaries paid to draftsmen, foremen and similar grades were not available. Furthermore, the Senate Committee report only included salaries of $5000 and over. Only a few of the salary figures given in the report were less than $5000. Considerable additional data relative to positions paying less than $5000 were obtained from a number of railroads, but the Sub-Committee was unable to check enough of these salary figures against individual careers to plot what it considers to be proper minimum and median curves for all positions in the mechanical department of a railroad. Therefore it must be assumed that Fig. 3 shows only the salaries paid to officers in the mechanical department of a railroad. It does not show the

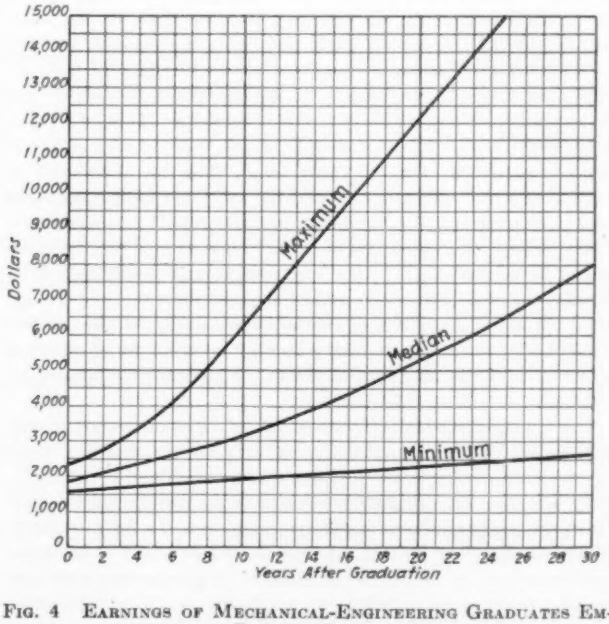


FIG. 4 EARNINGS OF MECHANICAL-ENGINEERING GRADUATES EMPLOYED BY RAILWAY-SUPPLY COMPANIES

salaries paid to officers in executive positions, neither does it show the salaries paid to men not holding some position of official capacity after five years out of college.

Fig. 4 shows the earnings of mechanical engineers employed by railway-supply concerns. The data for these curves were obtained from responsible officers of approximately 20 railway-supply companies. It will be noted that the maximum is higher than that for railroad employees in Fig. 3, but the median and minimum curves are considerably lower. This is due to the fact that complete data on all the mechanical engineers employed by these companies were reported and, of course, include the "square pegs in round holes," something which is not shown in Fig. 3 and, in all probability, not in Fig. 2. Of course, there being a considerably larger number of men working at salaries ranging around $3000 than at salaries of $6000, the median curve in Fig. 4 also is lower than those in Figs. 2 and 3. It is the opinion of the Sub-Committee that the salary situation as shown by the wide area between the maximum and minimum curves in Fig. 4 is a fairly accurate picture of the earnings of the mechanical engineer in industry, taken as a whole. Salaries paid at the present time have experienced no marked change since 1920.

Any attempt to obtain accurate data relative to salaries, such as those paid in the mechanical-engineering profession, presents a number of difficulties that should be taken into consideration when studying the salary data presented here. In the first place, all the men whose salaries are included in the figures are employed. No allowance has been made for those who are unemployed. Secondly, there is a greater possibility of obtaining salary figures from individuals in higher positions than from those who have made little or no progress in the profession. In all probability, curves showing average salaries paid would be much lower than those shown by the median curves in the three salary charts. In other words, a mechanical engineer of average ability can hardly assume that he will earn $4000 when ten years out of college and $6000 twenty years after graduation.

## Conclusion

It is the belief of the Railroad Division's Sub-Committee on Professional Service that if the young mechanical engineer or mechanical-engineering student is convinced that he will like railroad or railroad-supply work and has a special aptitude for such work he will succeed in getting ahead in either of the two allied industries. The degree of success depends largely on the characteristics and ability of the individual. This, of course, holds true for all industries as well as the railroad and railroad-supply industries. On the other hand, it is the consensus of opinion that both the railroads and the railway-supply companies need the young technical graduate, and this report would indicate that in salary and opportunity he can hope to achieve the same degree of success as in other engineering and industrial lines. Finally, the Sub-Committee wishes to stress the value of personal investigation in ascertaining the facts pertaining to the opportunities afforded in any industry he may be thinking of entering before arriving at any final decision, or committing himself to a definite line of work.

The appendixes which follow contain information for the benefit of those who wish to inquire further into the training and work for mechanical engineers on a number of Class I railroads. They also contain information relative to the training afforded by one of the leading railway supply companies, and a list of railway officers in charge of special apprentice work or heads of mechanical departments, to whom the student or graduate mechanical engineer can write relative to employment. For additional information, see the Pocket List of Railroad Officials, published quarterly by the Railway Equipment and Publication Company, 424 W. 33rd Street, New York.

(*Signed*)

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Joseph C. McCune, Assistant Director of Engineering, Westinghouse Air Brake Company, Wilmerding, Pa.

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## Appendix No. 1

LIST OF OFFICERS IN CHARGE OF APPRENTICES

A list of railroad officers in charge of special apprentices to whom the student or mechanical-engineering graduate should write for information relative to employment, follows. This list is subject to change, but can be brought up to date by comparing with the Pocket List of Railroad Officials and checking the title and address with the name. The company list, however, is permanent.

| Railroad | Name | Title | Address |
|---|---|---|---|
| **NEW ENGLAND REGION** | | | |
| Boston & Albany | F. A. Butler | Supt. M. P. & R. S. | Boston, Mass. |
| Boston & Maine | L. Richardson | Mech. Supt. | Boston, Mass. |
| N. Y., N. H. & Hartford | H. P. Hass | Asst. to Mech. Eng. | New Haven, Conn. |
| **GREAT LAKES REGION** | | | |
| Delaware & Hudson | G. S. Edmonds | Supt. M. P. | Albany, N. Y. |
| | G. W. Ditmore | M. C. B. | Albany, N. Y. |
| D. L. & W. | C. J. Scudder | Supt. M. P. & E. | Scranton, Pa. |
| Erie | W. S. Jackson | Supt. M. P. | 50 Church St., New York |
| Lehigh Valley | F. N. Hibbits | Supt. M. P. | Bethlehem, Pa. |
| Michigan Central | J. F. Jennings | Supt. M. P. | Detroit, Mich. |
| New York Central | W. H. Flynn | Genl. S. M. P. & R. S. | 466 Lexington Ave., New York |
| N. Y. C. & St. L. | T. W. Coe | Supt. M. P. | Prospect Ave. & E. 2nd St., Cleveland, O. |
| Pere Marquette | R. J. Williams | Supt. M. P. | Detroit, Mich. |
| Pitts. & Lake Erie | K. Berg | Supt. M. P. | McKees Rocks, Pa. |
| Wabash | G. F. Hess | Supt. M. P. | Decatur, Ill. |
| **CENTRAL EASTERN REGION** | | | |
| Baltimore & Ohio | A. G. Walther | Asst. Supt. Shops | Motive Power Dept., Baltimore, Md. |
| C. R. R. of N. J. | C. E. Chambers | Supt. M. P. | Jersey City, N. J. |
| Chic. & Eastern Ill. | L. S. Kinnaird | Supt. M. P. | Danville, Ill. |
| C. C. C. & St. L. | D. J. Mullen | Supt. M. P. | 506 Majestic Bldg., Indianapolis, Ind. |
| Elgin, Joliet & Eastern | J. Horrigan | Supt. M. P. | Joliet, Ill. |
| Pennsylvania | F. W. Hankins | Chief of M. P. | Broad St. Sta., Phila., Pa. |
| Reading | I. A. Seiders | Supt. M. P. & R. E. | Reading, Pa. |
| **POCAHONTAS REGION** | | | |
| Chesapeake & Ohio | J. W. Small | Chief Mech. Of. | Richmond, Va. |
| Norfolk & Western | A. Kearney | Supt. M. P. | Roanoke, Va. |
| Virginian | J. W. Sasser | Supt. M. P. | Princeton, W. Va. |
| **SOUTHERN REGION** | | | |
| Atlantic Coast Line | R. D. Hawkins | Genl. S. M. P. | Wilmington, N. C. |
| Central of Georgia | C. L. Dickert | Supt. M. P. | Savannah, Ga. |
| Florida East Coast | F. S. Robbins | Supt. M. P. & Mchy. | St. Augustine, Fla. |
| Illinois Central | R. W. Bell | Gen. Supt. M. P. | 135 E. 11th Pl., Chicago, Ill. |
| Louisville & Nashville | C. J. Bodemer | Act. Supt. Mach. | Louisville, Ky. |
| Seaboard Air Line | J. E. O'Brien | Ch. M. P. & E. | Savannah, Ga. |
| Southern | R. L. Ettenger | Asst. to V. P. | Washington, D. C. |
| **NORTHWESTERN REGION** | | | |
| Chicago & Northwestern | E. B. Hall | Gen. S. M. P. & M. | Keeler Ave. & Kinzie St., Chicago, Ill. |
| C. M. & St. P. | R. W. Anderson | Supt. M. P. | Milwaukee, Wis. |
| C. St. P. M. & O. | E. R. Gorman | Supt. M. P. & M. | St. Paul, Minn. |
| Great Northern | W. Kelly | Gen. S. M. P. | St. Paul, Minn. |
| M., St. P. & S. Ste. M. | T. A. Fogue | Gen. Mech. Supt. | Minneapolis, Minn. |
| Northern Pacific | S. Zwight | Gen. Mech. Supt. | St. Paul, Minn. |
| O. Wash. R. R. & Nav. Co. | C. E. Peck | Supt. M. P. & M. | Portland, Ore. |
| **CENTRAL WESTERN REGION** | | | |
| A. T. & S. F. | J. Purcell | Asst. to V. P. | 80 E. Jackson Blvd., Chicago, Ill. |
| Chicago & Alton | G. W. Seidel | Supt. M. P. & E. | Bloomington, Ill. |
| C. B. & Q. | J. H. Reisse | Mech. Asst. to V. P. | 547 W. Jackson Blvd., Chicago, Ill. |
| C. R. I. & P. | L. A. Richardson | Gen. Supt. M. P. | La Salle St., Chicago, Ill. |
| Chicago Great Western | E. J. Brennan | Supt. M. P. | Oelwein, Ia. |
| Denver & Rio Grande W. | W. J. O'Neill | Gen. Mech. Supt. | Denver, Col. |
| Oregon Short Line | A. C. Hinckley | Supt. M. P. & M. | Pocatello, Ida. |
| Southern Pacific | Geo. McCormick | Gen. S. M. P. | 65 Market St., San Francisco, Cal. |
| Union Pacific | E. J. Cole | Supt. of Shops | 11th & Cass St., Omaha, Neb. |
| Western Pacific | M. B. McPartland | Supt. M. P. | Sacramento, Cal. |
| **SOUTHWESTERN REGION** | | | |
| Gulf, Col. & S. Fe. | J. E. McQuillen | Mech. Supt. | Galveston, Tex. |
| Los Angeles & Salt Lake | Alfred Vesty | Apprentice Inst. | Los Angeles, Cal. |
| M. K. T. | H. M. Warden | Mech. Supt. | Parsons, Kan. |
| Missouri Pacific | D. A. Garber | Ch. Mech. Of. | St. Louis, Mo. |

| Railroad | Name | Title | Address |
|---|---|---|---|
| St. Louis-San Francisco | H. L. Worman | Supt. M. P. | Springfield, Mo. |
| Texas & New Orleans | J. A. Power | Supt. M. P. & E. | Houston, Tex. |
| Texas & Pacific | A. P. Prendergast | Mech. Supt. | Dallas, Tex. |
| | CANADA | | |
| Canadian Pacific | C. H. Temple | Ch. M. P. & R. S. | Montreal, Que. |
| Canadian National | C. E. Brooks | Ch. of M. P. | Montreal, Que. |

## Appendix No. 2

### INFORMATION RELATIVE TO EMPLOYMENT

A list of railway-supply-company officers to whom the student or mechanical-engineering graduate can write for information relative to employment, follows.

| Company | Name | Title | Address |
|---|---|---|---|
| Adams & Westlake Co. | W. H. Baldwin | Vice-Pres. | 319 W. Ontario St., Chicago, Ill. |
| Air Reduction Sales Co. | E. M. Sexton | R.R. Sales Mgr. | 346 Madison Ave., N. Y. C. |
| American Arch Co., Inc. | John P. Neff | Vice-Pres. | 17 E. 42nd St., N. Y. C. |
| American Brake Shoe & Fdry. | W. S. McGowan | Vice-Pres. | 30 Church St., N. Y. C. |
| American Car and Foundry Co. | Victor R. Willoughby | Gen. Mech. Eng. | 30 Church St., N. Y. C. |
| American Locomotive Co. | Joseph B. Ennis | Vice-Pres. | 30 Church St., N. Y. C. |
| American Ry. Appliance Co. | A. Schneider | President | 350 Madison Ave., N. Y. C. |
| American Steel Foundries | R. P. Lamont | President | Wrigley Bldg., Chicago, Ill. |
| Ashton Valve Co. | J. W. Motherwell | Vice-Pres. & Gen. Mgr. | Boston, Mass. |
| Baldwin Locomotive Works | R. S. McConnell | Ch. Eng. | Philadelphia, Pa. |
| Barco Manufacturing Co. | F. N. Bard | President | 1801 Winnemac Ave., Chicago, Ill. |
| Bethlehem Steel Company | J. M. DesIslets | Steel Car Div. | Bethlehem, Pa. |
| Bettendorf Co. | J. W. Bettendorf | President | Bettendorf, Ia. |
| Bird-Archer Co. | C. A. Bird | Vice-Pres. | 1 E. 42nd St., N. Y. C. |
| Bradford Corp. | A. F. Stuebing | Chief Engr. | 25 W. 43rd St., N. Y. C. |
| J. G. Brill Co. | J. L. Poultney | Mech. Eng. | 62nd St., Phila., Pa. |
| Buckeye Steel Castings Co. | S. P. Bush | President | Columbus, Ohio |
| Buda Company | F. E. Place | Vice-Pres. | Harvey, Ill. |
| Camel Co. | Fred. C. Heinen | Manager | 332 S. Michigan Ave., Chicago, Ill. |
| Chicago Ry. Equipment Co. | E. E. Griest | Gen. Supt. | 1928 W. 46 St., Chicago, Ill. |
| Cincinnati-Bickford Tool Co. | August H. Tuechter | President | Cincinnati, Ohio |
| Clark Car Co. | Chas. H. Clark | President | Oliver Bldg., Pittsburgh, Pa. |
| Commonwealth Steel Co. | C. H. Howard | President | Granite City, Ill. |
| Fairbanks, Morse & Co. | P. H. Gilleland | Mgr. R.R. Div. | 900 S. Wabash Ave., Chicago, Ill. |
| Franklin Ry. Supply Co. | Chas. G. Carothers | Mech. Eng. | 17 E. 42nd St., N. Y. C. |
| Gold Car Heating & Lighting Co. | E. B. Wilson | Vice-Pres. | 220 36th St., Brooklyn, N. Y. |
| Gould Coupler Co. | C. J. Symington | President | Md. Trust Bldg., Baltimore, Md. |
| Hunt-Spiller Mfg. Corp. | W. B. Leach | Pres. & Gen. Mgr. | 383 Dorchester Ave., Boston, Mass. |
| Hyatt Roller Bearing Co. | H. J. Forsythe | President | Newark, N. J. |
| Illinois Car & Mfg. Co. | ........... | ....... | Hammond, Ind. |
| Ingersoll-Rand Co. | L. G. Coleman | Mech. Eng., R.R. Div. | 11 Broadway, N. Y. C. |
| Johns-Manville | Geo. A. Nicol, Jr. | Gen. Mgr., R.R. Dept. | 292 Madison Ave., New York, N. Y. |
| R. K. LeBlond Mch. Tool Co. | John A. LeBlond | Vice-Pres. | Madison Road, Cincinnati, Ohio |
| Lima Locomotive Works | W. E. Woodard | Vice-Pres. | 17 E. 42nd St., N. Y. C. |
| Locomotive Firebox Co. | B. E. Larson | Mech. Eng. | 310 S. Michigan Ave., Chicago, Ill. |
| Lukens Steel Co. | D. S. Wolcott | Asst. to Pres. | Coatesville, Pa. |
| Magor Car Corp. | A. Van Hassel | Vice-Pres. | 30 Church St., N. Y. C. |
| Manning, Maxwell & Moore, Inc. | Frank J. Baumis | Vice-Pres. | 100 E. 42nd St. N. Y. C. |
| W. H. Miner, Inc. | W. H. Miner | President | 209 S. LaSalle St., Chicago, Ill. |
| New York Air Brake Co. | Richard B. Sheridan | Vice-Pres. | 165 Broadway, N. Y. C. |
| Niles-Bement-Pond Co. | J. K. Cullen | President | 111 Broadway, N. Y. C. |
| Ohio Brass Co. | L. W. Birch | Line Matl. Eng. | Mansfield, Ohio |
| Oxweld R.R. Service Co. | Chas. B. Moore | Vice-Pres. | 350 Ry. Ex. Bldg., Chicago, Ill. |
| Pressed Steel Car Co. | Huntley H. Gilbert | Gen. Sales Mgr. | 134 LaSalle St. Chicago, Ill. |
| Pullman Car & Mfg. Corp. | Peter Parke | Chief Engr. | Pullman Bldg., Chicago, Ill. |
| Q. & C. Co. | F. F. Kister | President | 90 West St., N. Y. C. |
| Railroad Supply Co. | E. H. Bell | President | 203 S. Dearborn St., Chicago, Ill. |
| Railway Motors Co. | L. W. Melcher | ....... | DePere, Wis. |
| S. K. F. Industries, Inc. | W. L. Batt | President | 40 E. 34th St., N. Y. C. |
| Safety Car Heating & Lighting Co. | J. H. Dixon | Vice-Pres. | 75 West St., N. Y. C. |
| St. Louis Car Co. | ........... | ....... | 8000 N. Broadway, St. Louis, Mo. |
| Sinclair Refining Co. | Clifford M. Larson | Supvr. Eng. Ry. Sales Dept. | 45 Nassau St., N. Y. C. |
| Standard Steel Car Co. | John H. Mitchell | Mgr. Sales | 1120 Frick Bldg., Pittsburgh, Pa. |
| Standard Stoker Co. | F. C. Pickard | Works Mgr. | Erie, Pa. |
| Superheater Co. | H. B. Oatley | Vice-Pres. | 17 E. 42nd St., N. Y. C. |
| Symington Co. | C. J. Symington | President | 250 Park Ave., N. Y. C. |
| Timpken Roller Bearing Co. | W. C. Sanders | Gen. Mgr., Ry. Div. | Canton, Ohio |
| Union Draft Gear Co. | L. T. Canfield | Vice-Pres. | 332 S. Michigan Ave., Chicago, Ill. |
| Union Tank Car Co. | Jos. J. Root | Asst. to Vice-Pres. | 134 N. LaSalle St., Chicago, Ill. |
| U. S. Steel Corp. | John Hulst | Asst. to Vice-Pres. | 71 Broadway, N. Y. C. |
| Vapor Car Heating Co., Inc. | Egbert H. Gold | President | 80 E. Jackson Blvd., Chicago, Ill. |

| Company | Name | Title | Address |
|---|---|---|---|
| Walworth Co. | Howard Coonley | President | Box 26, Boston, Mass. |
| Westinghouse Air Brake Co. | C. C. Farmer | Director of Engineering | Wilmerding, Pa. |
| Westinghouse Friction Draft Gear Company | S. G. Down | President | Wilmerding, Pa. |
| Whiting Corp. | T. S. Hammond | President | Harvey, Ill. |
| Worthington Pump & Mchy. Corp. | Fred. A. Pope | Supvr. Training | 115 Broadway, N. Y. C. |

## Appendix No. 3

### OUTLINE OF TRAINING COURSES

The following material constitutes an outline of the courses of training given by 20 railroad companies and one railway-supply company to prepare graduates in mechanical engineering for work in the mechanical or motive-power departments. These courses are generally known as special apprentice courses. A number of the companies from which this information was obtained have requested that their identity with the course not be published. The majority of the railroads have an agreement with the shop crafts limiting the total of special, regular, and helper apprentices to five per cent of the total number of machinists and helpers employed. Information relative to any of the courses listed in this Appendix may be obtained by writing to the chairman of the Sub-Committee on Professional Service, Railroad Division, A.S.M.E., 29 W. 39th St., New York.

### RAILROAD "A"

Special apprentices are selected from young men between the ages of 18 and 26 years, who have had a technical-school education and who pass an examination on engineering principles. They must serve a period of three years of 290 days each calendar year, during which time they receive training in the various departments in the different classes of work of the crafts employed in the Maintenance of Equipment department.

If retained in the service at the completion of the three-year course, they select the craft they desire employment in and are given training in the work of the craft selected for the period of one year. During this period, special apprentices are allowed a special rate. At the completion of four years, each special apprentice is classified and he receives the minimum rate of the craft in which he is employed until a vacancy occurs in the supervisory staff.

The rates paid special apprentices are as follows:

| Year | Period | Hourly rate |
|---|---|---|
| First | First six months | $0.52 |
| | Second six months | 0.545 |
| Second | First six months | 0.57 |
| | Second six months | 0.595 |
| Third | First six months | 0.62 |
| | Second six months | 0.65 |
| Fourth | Year | 0.69 |

Special apprentices are promoted to fill vacant minor supervisory positions, their selection and promotion depending entirely on their individual ability and qualifications.

In addition to the shop training, beginning September 1, 1927, this road extends its regular apprentice technical training to the special apprentices. This training gives special instructions pertaining to the work of the various crafts. Special apprentices will, like the regular and helper apprentices, be required to follow a progressive study period and do their studying and prepare their examinations on their own time. The rules of the shop crafts' agreement make this technical training compulsory and each apprentice must submit a minimum of two lessons each month.

This railroad employs the Railway Educational Bureau, Omaha, Neb., to furnish technical training to all regular and helper apprentices. This bureau furnishes the necessary texts and instruction papers to the apprentices, corrects and grades the lessons which are prepared by the apprentices at home; also furnishes the railroad with a monthly report showing the lessons submitted by each apprentice, together with the grades made. All apprentices are required to follow a progressive study schedule and complete two lessons each month. They do their studying and prepare their examinations on their own time.

The technical training of apprentices is directed from the office of the chief of motive power and equipment, where an organization, in charge of the assistant supervisor of shops, supervises the apprentice training and maintains monthly reports showing the individual progress of each apprentice. This technical training was made compulsory prior to putting this plan into effect.

Schedule for Special Apprentices Showing the Time Assigned to Various Classes of Work in the Different Shops and Departments

| | |
|---|---|
| *Erecting Shop* | |
| Tool room (issuing tools)—To obtain general knowledge of tools | 1/2 mo. |
| Steam-tight gang—On checks, pops, whistles, gage cocks, etc. | 1 mo. |
| Steam-pipe gang—On steam pipes, dry pipes, throttle boxes and rigging, etc. (1 week to be spent on grinding and assembling and the remainder on erecting) | 1 mo. |
| Brake rigging | 1/2 mo. |
| Frame gang—Cylinder—1 week; Boiler pads—1 week; Frames and braces—1/2 month | 1 mo. |
| Shoe and wedge gang | 1 mo. |
| Valve gang | 1 1/2 mo. |
| Guide gang | 1/2 mo. |
| Total | 7 mo. |
| *Machine Shop* | |
| Wheel and eccentric gang | 1 mo. |
| Box gang | 1/2 mo. |
| Main and side rods, and crossheads | 1 1/2 mo. |
| Valves | 1/2 mo. |
| Links | 3/4 mo. |
| Throttle rigging and reverse bars | 3/4 mo. |
| Miscellaneous machine work, lathe, planer, boring mill, etc. | 2 mo. |
| Total | 7 mo. |
| *Tool Department* | |
| General machine work | 1 mo. |
| *Air Brake Shop* | |
| Injectors | 1/2 mo. |
| Pop or relief valves | 1/4 mo. |
| Triple valves | 1/4 mo. |
| Engineer's valves | 1/4 mo. |
| Air compressors | 3/4 mo. |
| Total | 2 mo. |
| *Boiler Shop* | |
| Laying out | 1/2 mo. |
| Fitting up | 1/2 mo. |
| General boiler work | 3 mo. |
| Total | 4 mo. |
| *Car Department* | |
| Passenger-car truck work | 1/2 mo. |
| Passenger-car body work | 1/2 mo. |
| Passenger car interior work | 1 mo. |
| Freight track (special work under foreman to get a general idea of car work) | 1 mo. |
| Inspection—Air brakes | 1/2 mo. |
| Inspection—General | 1/2 mo. |
| Total | 4 mo. |
| *Drawing Room* | |
| Freight-car work | 1 mo. |
| Passenger-car work | 1 mo. |
| Locomotive work | 1 mo. |
| (This work to be as general as possible in all three departments) | |
| Total | 3 mo. |
| *Special Work* | |
| Routing system | 1 mo. |
| Shop order | 1/2 mo. |
| Test department (general) | 1 mo. |
| Cost statements | 1/2 mo. |
| Total | 3 mo. |

*Enginehouse*

| | | |
|---|---|---|
| Inspectors | 1/2 | mo. |
| Passenger engines | 1 | mo. |
| Freight engines | 1 | mo. |
| Laid-in gang | 1/2 | mo. |
| Road foreman | 2 | mo. |
| Total | 5 | mo. |

(Work at enginehouses to be distributed on repairs of all parts of engines.)

The assignment of work for the fourth year will be as per special chart for each craft.

Division of Time on Various Classes of Work in Different Grades for Special Apprentices During Fourth Year of Their Apprenticeship

(Special apprentice to choose the craft he desires prior to entering on fourth year.)

*Machinist Craft*

*A*—2 months—air-brake work
*B*—2 months—tool room—tool and die work
*C*—3 months—machine shop—bench and machine work
*D*—3 months—erecting shop—valve, frame, steam and trimming
*E*—2 months—autogenous welding

*Boilermaker Craft*

*A*—2 months—laying out—locomotive boiler, firebox and car sheet metal parts
*B*—2 months—flanging—boiler and firebox parts
*C*—2 months—assembling—boiler and firebox sheets
*D*—2 months—applying stay, radial and flexible bolts—tapping and driving
*E*—2 months—caulking and chipping
*F*—2 months—autogenous welding

*Carmen Craft*

*A*—4 months—freight car department
*B*—2 months—saw mill and cabinet shop
*C*—1 month—passenger car finishing shop
*D*—2 months—passenger car pipe shop
*E*—3 months—passenger car erecting shop

Statement Showing Status of Special Apprentices on Railroad "A"—August 1, 1927

| | |
|---|---|
| Total number authorized | 35 |
| Total number employed since December, 1921[10] | 66 |
| Number left service prior to completing course | 17 |
| Number completed course to date | 19 |
| Number now serving | 30 |

The following shows present status of the 19 who completed courses: eight are not in supervisory positions and ten are working as mechanics on special work at mechanic's rate.

## RAILROAD "B"

### Special Apprenticeship Course

The purpose of the course is to train for official positions in the motive power department graduates in mechanical engineering from universities or colleges whose courses of study in that branch of engineering fit young men to meet our requirements. Application for appointment as special apprentice is made to the chief of motive power, in the handwriting of the applicant on a special form accompanied by a recent photograph of the applicant. If the application is favorably considered, the applicant is given a personal interview by the chief of motive power before a final decision as to his appointment is reached.

In selecting the young men consideration is given not only to the educational requirements, but also to their personality, physique, and general make-up. Railroad "B" especially desires to secure men with initiative who are interested in and willing to work to learn the railroad business. The course covers a period of three years, divided between the various departments at the principal repair shops of the company, and on the road, as follows:

| | | |
|---|---|---|
| Erecting shop | 6 | mo. |
| Machine shop | 5 | mo. |
| Air-brake shop | 2 | mo. |
| Blacksmith shop | 1 | mo. |
| Iron foundries | 2 | mo. |
| Enginehouse | 4 1/2 | mo. |
| Car shop | 3 | mo. |
| Division superintendent | 3 | mo. |
| Boiler shop | 3 | mo. |
| Firing | 2 | mo. |
| Office road foreman of engines | 1 | mo. |
| Storehouse | 1 | mo. |
| Office of supervisor of expenditures | 1 1/2 | mo. |
| Car-interchange rules | 1 | mo. |
| Total | 36 | mo. |

At the present time the rate of pay for the first six months is 55 cents per hour (208 hours a month), increasing two cents an hour each six months to 65 cents per hour for the final period.

Special apprentices are carried on the payroll the same as other employees, and are paid only for the time worked, no provision being made for vacation.

During his course, the special apprentice is brought into more or less close contact with the officials and learns something of the ethical side of the requirements of an officer of the company.

While there is no contract requiring them to do so, it is, of course, expected that young men taking this course intend to continue in the railroad's service. Upon completion of the course, special apprentices are assigned as motive power inspectors, or as gang foremen in enginehouses, for which positions the present salaries are $230 and $238, respectively, a month. Their subsequent advancement depends upon the general ability and fitness displayed and the openings that may occur in the organization. The line of promotion is usually assistant master mechanic, assistant engineer of motive power, master mechanic, superintendent of motive power, etc.

## RAILROAD "B"

### Special Apprenticeship Courses

*Erecting Shop*

| | | |
|---|---|---|
| General erecting shop work with machinist | 4 | mo. |
| Driving boxes and link work | 3 | wks. |
| Steam pipes, throttles, and air-brake fittings | 3 | wks. |
| Iron pipes and back-head fittings | 2 | wks. |
| Total | 6 | mo. |

*Machine Shop*

| | | |
|---|---|---|
| Planer, by himself | 1 | mo. |
| Slotter, by himself | 1 | mo. |
| Boring mill | 1/2 | mo. |
| Bench work on main rods | 1/2 | mo. |
| Lathe, by himself | 1 | mo. |
| Bench work on links, crossheads, pistons | 1/2 | mo. |
| Laying-off table | 1/2 | mo. |
| Total | 5 | mo. |

*Air-Brake Shop*

| | | |
|---|---|---|
| Injectors | 1 | wk. |
| Triple valves | 1 | wk. |
| Lubricators and retaining valves | 1 | wk. |
| Test racks | 1 | wk. |
| Pump and top heads | 1 | wk. |
| Brake and feed valves | 1 | wk. |
| Regulators, high-speed reducing valves | 2 | wks. |
| Total | 2 | mo. |

*Blacksmith Shop*

| | | |
|---|---|---|
| Hand forge on miscellaneous work | 2 | wks. |
| Hand forge on tools | 1 | wk. |
| Spring shop | 1/2 | wk. |
| Forge or hammer shop | 1/2 | wk. |
| Total | 1 | mo. |

(Apprentices to be given an elementary knowledge of hand forging. Special emphasis to be placed on the dressing and tempering of tools.)

[10] The United States Railroad Labor Board handed down a rule authorizing the employment of special apprentices, effective December 1, 1921.

*Iron Foundries*

| | | |
|---|---|---|
| Cupola | 2 | wks. |
| Helping molders on miscellaneous work | 2 | wks. |
| On cylinders helping molders | 2 | wks. |
| On pipes helping molders | 1 | wk. |
| Wheel foundry helping molders | 1 | wk. |
| Total | 2 | mo. |

*Enginehouse*

| | | |
|---|---|---|
| Machinist gang | 2½ | mo. |
| Air brake gang | ½ | mo. |
| Inspection pit | ½ | mo. |
| Work distributor | ½ | mo. |
| Cleaning fires and moving engines | ¼ | mo. |
| Office work, chasing power | ¼ | mo. |
| Air-brake instruction room | — | |
| Total | 4½ | mo. |

*Car Shops*

| | | |
|---|---|---|
| Freight cars (new and repair work, attending wrecks) | 1 | mo. |
| Steel car shop (all operations on runway and miscellaneous work, including running of machines) | 1 | mo. |
| Passenger cars, new and repair work | 1 | mo. |
| Total | 3 | mo. |

*Interchange and Inspection*

| | | |
|---|---|---|
| Car inspection, classification yard (inspecting freight cars, 2 weeks; inspecting passenger cars, 2 weeks) | 1 | mo. |
| Freight car repairs, outside (with gang on repairs, 1 month; with inspector, 1 month) | 2 | mo. |
| Instruction to be given in M.C.B. work | — | |
| Total | 3 | mo. |

*Boiler Shop*

| | | |
|---|---|---|
| Staying, stays and crown bolts | 3 | wks. |
| Bracing | 1 | wk. |
| Patching | 2 | wks. |
| Inspecting in yard and enginehouse | 3 | wks. |
| Flue work | 2 | wks. |
| Sheet iron work | 1 | wk. |
| Total | 3 | mo. |
| Firing freight and passenger runs (assignment of runs to be made by road foreman of engines) | 2 | mo. |
| Office of road foreman of engines | 1 | mo. |

*Storehouse*

| | | |
|---|---|---|
| Storehouse | 1 | wk. |
| Receiving and shipping department | 1 | wk. |
| Main storehouse office | 2 | wks. |
| Total | 1 | mo. |

(Apprentices in this department shall be given the opportunity to familiarize themselves with the methods of ordering, receiving and giving out material, together with the records and forms used. They should be taught methods of keeping account of stock and how to maintain a reasonable supply.)

### Shop Accounts

| | | |
|---|---|---|
| Time accounts | 1 | wk. |
| Labor distribution | 1 | wk. |
| Tabulating room | 1 | wk. |
| Cost accounts | 1 | wk. |
| Expense accounts | 1 | wk. |
| Inventory | 1 | wk. |
| Total | 1½ | mo. |

### M.C.B. Interchange

| | | |
|---|---|---|
| Instructions and car interchange rules | 1 | wk. |
| Checking A.R.A. billing repair cards | 1 | wk. |
| Writing A.R.A. car repair bills | 1 | wk. |
| Reports of foreign bad orders and destroyed cars and general interchange matters | 1 | wk. |
| Total | 1 | mo. |

## RAILROAD "C"

Provision is made for a limited number of special apprentices who, as a rule, are required to be graduates of recognized colleges in engineering courses. They are given a general experience in the shops and enginehouses and in road tests and other operations of major importance in railroad mechanical operation. We stress the enginehouse experience as it is in the terminal operations that the individual, in our view, has the best opportunity for his own advancement and of prospective value to us.

If the apprentice has the qualities of success in him he will sooner acquire a true railroad perspective in the enginehouse than in the back shop. We give special apprentices who do not gravitate to the engineering department or some other staff positions a well-rounded experience in all departments of mechanical operation.

Special apprentices are started at 55 cents an hour, at the end of the first year they are raised to 65 cents and advanced to journeyman's rate of 75 cents an hour at the end of the second year. In other words, they get journeyman's rate for the third and last year of apprenticeship. Special apprentices are supervised in general through the superintendent of apprentices through the line officers in charge of our mechanical operations.

## RAILROAD "D"

The following is the information relative to the special apprentice training given by Railroad "D:"

### First Year

Salary—First 6 months, $120; Second 6 months, $124.

(Experience on the regular work in the shops, with change of work approximately every three months.)

### Second Year

Salary—First 6 months, $128; Second 6 months, $132.

(Experience on the regular work in the shops with special assignment, as opportunity offers, to dynamometer car tests and other special duty.)

### Third Year

Salary—First 6 months, $136; Second 6 months, $140.

(Experience on the regular work in the shops, with a period in the enginehouse. Special duty assignments leading to supervisory positions.)

## RAILROAD "E"

### Special Apprentice Course for Mechanical Engineers

#### First Year

Salary—53 and 55 cents per hr.

| Work | No. of weeks |
|---|---|
| Stripping | 2 |
| Machine shop | 8 |
| Wheel shop | 4 |
| Rods, crossheads, etc. | 5 |
| Accessories | 8 |
| Air brakes | 8 |
| Boilers | 9 |
| Spring and brake rigging | 4 |
| Total | 48 |

#### Second Year

Salary—57 and 59 cents per hr.

| | |
|---|---|
| Frames | 8 |
| Trucks | 2 |
| Valve motion | 6 |
| Erecting shop | 5 |
| Tank shop | 2 |
| Enginehouse | 13 |
| Electric locomotive repair shop | 12 |
| Total | 48 |

#### Third Year

Salary—61 and 63 cents per hr.

| | |
|---|---|
| Central power station | 8 |
| Gasoline rail-car shops | 12 |
| Drafting room | 12 |
| Department of tests | 12 |
| Mechanical Engineer's Office | 4 |
| Total | 48 |

## RAILROAD "F"

Special apprentices shall be selected from young men between the ages of 18 and 26 years, who have had at least two years technical school training and shall serve three years of 290 days, or the equivalent in hours, each calendar year. Special apprentices shall receive training in the various departments in the different classes of work of the different crafts in the maintenance of equipment and may be moved from place to place, or on any class of work for the first 18 months. The last 18 months to be devoted to such work as conditions will permit.

## RAILROAD "G"

The course for special apprentices is covered by an agreement between the company and the shop crafts employees, the requirements being as outlined:

"Special apprentices shall be selected from young men between the ages of 18 and 26 years who have had a technical-school education and shall serve three years of 290 days, each calendar year. They shall receive training in the various departments in the different classes of work of the different crafts in the maintenance-of-equipment department and may be moved from place to place or on any class of work at the discretion of the management.

"In computing the ratio of apprentices to mechanics, special apprentices will be included, the number of same not to exceed five per cent of the total. If retained in the service at the completion of the three-year course, the apprentice may choose the craft he desires employment in and shall receive a special rate for the period of one year, at the expiration of which time he shall be classified and receive the minimum rate of the craft employed in. The rate of pay for special apprentices for the first three years shall be not less than that of helper apprentices."

Special apprentices report either to the superintendent of shops or to the mechanical engineer depending on the particular assignment on which they may be working. Generally they are started in the mechanical engineer's office or the shop drafting office on drawing files and other drafting work. Some are placed in the shops at various trades, others continue in the drafting office filling vacancies that occur in the ranks of junior draftsmen.

While it is desired to give all special apprentices a chance to work in all departments of the shops, it is not always possible to do so as when vacancies occur in the ranks of draftsmen, we select the more competent and promote them to these positions. The ones that finally complete the course are generally found to be valuable material for promotion to ranks of shop supervisors.

Railroad "G" has no particular course of study for special apprentices except the training they get in the shops. Being selected from the ranks of technical graduates, they usually are much further advanced than other apprentices and are not required to attend school. Their selection for shop supervisors and other positions of trust and responsibility depend entirely on their ability and experience. Seniority as a rule has nothing to do with promotion except of course, where ability and experience are approximately equal.

The rates of pay are as follows: First six months, 48 cents per hour, with a 2-cent increase each six months thereafter for the first six periods. After completion of the third year, special apprentices are given a special rating for one year.

First Year

Salary—48 cents and 50 cents per hr.

| Work | Weeks |
|---|---|
| Machine shop | 17 or 18 |
| Erecting shop | 17 or 18 |
| Boiler shop | 17 or 18 |

Second Year

Salary—52 cents and 54 cents per hr.

| | |
|---|---|
| Blacksmith shop | 17 or 18 |
| Electric shop | 17 or 18 |
| Foundry | 17 or 18 |

Third Year

Salary—56 cents and 58 cents per hr.

| | |
|---|---|
| Drawing room | 17 or 18 |
| Schedule department | 17 or 18 |
| Locomotive tests | 17 or 18 |

Fourth Year

Salary—special rates are set for individuals by the shop superintendent or master mechanic.

Special work depending on man's ability ......... 52

## RAILROAD "H"

First Year

Salary—50 cents and 55 cents per hr.

| Work | Weeks |
|---|---|
| In machine shop—all classes of work | |
| Machine shop practices | |

Second Year

Salary—60 cents and 65 cents per hr.

Erecting shop practices and finishing machine shop practices

## RAILROAD "J"

First Year

Salary—30 cents and 33 cents per hr.

| Work | Weeks |
|---|---|
| *Machine Shop* | |
| Drill press | 8 |
| Engine lathe | 12 |
| Draw-cut shaper | 8 |
| Turret lathe | 8 |
| Brass lathe | 8 |
| Frames | 4 |
| Welding | 4 |

Second Year

Salary—37 cents and 40 cents per hr.

| | |
|---|---|
| *Erecting Shop* | |
| Cab work | 2 |
| General floor | 4 |
| Rods | 8 |
| Motion work | 10 |
| Shoes and wedges | 4 |
| Air room | 8 |
| Valves | 8 |
| Cross heads | 4 |
| Tool room (milling machine) | 4 |

Third Year

Salary—40 cents and 44 cents per hr.

| Work | Weeks |
|---|---|
| *Boiler Shop* | |
| Flange fire | |
| General boiler work and laying out | 24 |
| *Blacksmith Shop* | |
| Light fire | |
| Bulldozer and heavy forging | 24 |

Fourth Year

Salary—51 cents and 58 cents per hr.

| | |
|---|---|
| *Car Department* | |
| Air and heavy repairs | 24 |
| *Mill and A.R.A.* | |
| Enginehouse, general work and inspecting | 24 |

## RAILROAD "K"

Technical graduates who are accepted as special apprentices put in certain time in the drafting room, after which they are transferred to different shop points on the railroad where they work in various departments of the shop operation. As a general thing they are occasionally given special assignments such as economic studies for new equipment and improvements, and some test work. An attempt is made to keep them in the shop on actual work to the greatest extent possible.

The maximum number of special apprentices are limited to 20 for the system, divided equally between the locomotive and car departments and distributed at the principal points, in proportion to the force employed and the facilities for educating the apprentices involved.

The rates of pay will be increased annually instead of semi-annually as heretofore, as follows:

| | |
|---|---|
| First year | 62 cents per hr. |
| Second year | 65 cents per hr. |
| Third year | 68 cents per hr. |
| Fourth year | 72 cents per hr. |

Two hundred and ninety days actual service constitute a year. Overtime or sick leave is not included, except in special cases where the circumstances warrant modification, and only then after approval by the head of the mechanical department.

The greatest possible care is exercised in selecting special apprentices. A college education with diploma signifying completion of an approved course is not necessary, but is desirable. All applicants for the position of special apprentice should possess the qualifications for obtaining education that will enable them to absorb problems of a technical nature, and each applicant must be approved by the head of the mechanical department.

Special apprentices are not to be used on work other than what is outlined below, except in such cases as are authorized by the head of the mechanical department. The following schedules are outlined to guide in as practical a manner as possible, the diversity of service to which special apprentices should be assigned. Deviation is permitted as will best fit the ability of the individual apprentice and the facilities and circumstances obtaining:

SPECIAL APPRENTICE (STEAM TRAINING)

| | | |
|---|---|---|
| General machine work | 9 | mo. |
| General floor work | 12 | mo. |
| Special work | 15 | mo. |
| Minor supervisory work | 12 | mo. |

SPECIAL WORK

| | | |
|---|---|---|
| Enginehouse | 8 | mo. |
| Boiler shop | 2 | mo. |
| Blacksmiths shop | 1 | mo. |
| Powerhouse | $1\frac{1}{2}$ | mo. |
| Car shop and tender work | $2\frac{1}{2}$ | mo. |
| Total | 15 | mo. |

SPECIAL APPRENTICE (ELECTRICAL TRAINING)

| | | |
|---|---|---|
| Electrical engineers' office | 3 | mo. |
| General backshop work on electrical equipment, including control, relays, grids, etc. | 9 | mo. |
| General backshop machine work and erecting | 3 | mo. |
| Armature work | 3 | mo. |
| Batteries | 1 | mo. |
| Meters | 1 | mo. |
| Enginehouse (mech. and elec.) | 4 | mo. |
| Test track | 2 | mo. |
| Substation—operation and maintenance | 2 | mo. |
| Load dispatching and time spent with electrical instructor | 3 | mo. |
| Special assignments | 5 | mo. |
| Minor supervisory work | 12 | mo. |
| Total | 48 | mo. |

SPECIAL CAR DEPARTMENT APPRENTICE

| | | |
|---|---|---|
| Heavy repair track | $12\frac{3}{4}$ | mo. |
| Air-brake shop | $2\frac{1}{2}$ | mo. |
| Train yard | 1 | mo. |
| Coach yard | $1\frac{3}{4}$ | mo. |
| Wrecking outfit | $\frac{1}{2}$ | mo. |
| Wood mill | 1 | mo. |
| Blacksmith shop | 2 | mo. |
| Machine shop | 2 | mo. |
| Coach shop | $9\frac{1}{2}$ | mo. |
| Drafting room | 3 | mo. |
| Minor supervisory work | 12 | mo. |
| Total | 48 | mo. |

During the last 12 months, special apprentices are assigned in a minor supervisory capacity. It is intended by this assignment to develop the executive ability of special apprentices and give them an opportunity to prepare themselves for supervisory positions. It is the railroad's desire to arbitrarily make these specific assignments so that the special apprentice will direct and be responsible for not only his work, but that of such other employees as may be placed under his direct supervision. Definite assignments of this character are worked out as occasion requires.

## RAILROAD "L"

This railroad has had a course for special apprentices for about 20 years. It consists of a three-year course divided into six periods of six months each. Special apprentices must be graduates in mechanical engineering from schools of recognized standing, and the railroad prefers to have them enter its employ immediately after graduation. No applicants will be accepted after one year out of college. Each applicant must pass a physical examination similar to that required of enginemen and firemen, which is given by the company surgeon.

The first year of the course is as follows: Operating machines with one month assignment to special work for a master mechanic, mechanical superintendent, mechanical engineer, or the engineer of tests.

Second year: Floor, bench and erecting work, with one month of special work.

Third year: Two months boiler-shop work, two months freight-car shop, four months enginehouse, two months with a road foreman of engines, and two months inspecting locomotives.

The rates of pay are as follows:

| | |
|---|---|
| First six months | 53 cents per hr. |
| Second six months | $55\frac{1}{2}$ cents per hr. |
| Third six months | 58 cents per hr. |
| Fourth six months | $60\frac{1}{2}$ cents per hr. |
| Fifth six months | 63 cents per hr. |
| Sixth six months | $65\frac{1}{2}$ cents per hr. |

The following outside reading is recommended but not required: Locomotive and car folios of company standards, American Railway Association rules, company and Interstate Commerce Commission rules for the maintenance of locomotives and boilers, railroad operating rules, the *Railway Age*, own and use a good handbook such as Kent's, Machinery's, Marks', etc. A monthly letter is required from each special apprentice during his third year outlining the work he has done, with his comments, criticisms, and suggestions. Each special apprentice has the privilege of selecting the department in which he prefers to work on the completion of his course. Promotion depends entirely on individual ability. If two possess the same qualities or ability, promotion is then made according to seniority.

Promotion to supervisory positions in the shops or to permanent positions in the mechanical engineer's office, engineer of tests, or to apprentice instructor is made as soon as vacancies occur. Sometimes a promotion is made immediately, sometimes after one or two years, and sometimes never.

The following remarks were included at the end of the report on special training which was received from this road: "The course of training, while necessary for railroad work, appears too long when compared with the training in industrial plants. The immediate compensation is less, but the ultimate reward is fully as much."

## RAILROAD "M"

This railroad maintains a three-year special apprentice course. It consists essentially of three months on the erecting floor, two years in the machine shop, seven months on erecting and inspection work, and two months in the enginehouse.

The rates of pay are as follows:

| | |
|---|---|
| First six months | 51 cents per hr. |
| Second six months | 53 cents per hr. |
| Third six months | 55 cents per hr. |
| Fourth six months | 57 cents per hr. |
| Fifth six months | 59 cents per hr. |
| Sixth six months | 61 cents per hr. |

Seniority in line of promotion is not considered in the advancement of special apprentices. Ability, a combination of knowledge, experience, and the execution of common sense are the chief assets.

## RAILROAD "N"

Only graduates from technical schools of recognized standing are accepted as special apprentices by this road. No drafting-room work is included in the course of training, nor is the course confined entirely to work in the shop. Special apprentices are used largely as assistants in the compilation of test data and information, and work of similar nature. However, an opportunity is provided to obtain some of the regular apprentice training under an agreement with the shop crafts. Promotion is about the same as that for foremen in the majority of cases. A number, however, are assigned to work in the test department on completion of their course, or are assigned to duty as mechanics or to some other form of employment.

## RAILROAD "O"

This railroad has had a two-year special apprentice course in

operation for about two years. In this course, 145 days are spent on machine and bench work, divided as follows: 12 days on a planer, 12 days on a boring mill, 12 days on a shaper, 40 days on lathes, 10 days on a rod bench, 14 days on boiler mountings, 10 days at power plant, and 12 days on the link bench. A period of 145 days is spent on the erecting floor, divided up as follows: 14 days, shoes and wedges; 10 days, cylinders and frames; 13 days, guides and pistons; 14 days, driving boxes; 48 days, valves; 16 days, wheel gang; 14 days, cab work; 10 days, special work. (Total of 2320 shop hours constitutes the work of the first year.) Second Year—24 days on gas and electric welding; 74 days, enginehouse work of which 20 days are spent in general helping; 30 days running work and 24 days on air-brake and machinery inspection; 86 days are spent in the boiler shop of which 22 days are devoted to flues and arch tubes; 16 ash pans and grates; 12 days on the lay-out bench; and 36 days on firebox and boiler shell. Seventy-two days the special apprentice works in the freight-car shop, 12 of which are spent on trucks, couplers, and draft gears; 36 days on wood and body work; 24 days on steel-car work; (total of 2320 shop hours for the second year, including following road and special work; 14 days riding locomotives with the road foreman of engines and 20 days on special work).

The rates of pay are as follows:

| | |
|---|---|
| First six months | 50 cents per hr. |
| Second six months | 55 cents per hr. |
| Third six months | 60 cents per hr. |
| Fourth six months | 65 cents per hr. |

In the promotion of special apprentices, seniority counts for little. Experience is desired; ability the main factor. The special apprentice is not expected to handle supervisory work on the completion of his course, but receives consideration when vacancies arise. Graduates rate a mechanical assistant's pay at $175.00 per month. They fill vacancies as foremen, are assigned to the dynamometer car, etc. They also work on test, in the physical test laboratory and in the drafting room. Men working on these assignments are kept at this kind of work until a vacancy occurs in some supervisory position. These positions are considered in somewhat the light of a post-graduate special apprentice course, and is considered valuable experience.

## RAILROAD "P"

This railroad has two courses which are designated "Course A" and "Course B." "Course A" is a three-year course for college graduates and "Course B" is a five-year course for especially bright and studious regular apprentices. The following table shows the time spent in the various departments for both courses.

| | Time, A | Months. B |
|---|---|---|
| Machine shop | 10 | 18 |
| Erecting shop | 10 | 18 |
| Blacksmith shop | 4 | 6 |
| Drafting room | 4 | 6 |
| Boiler shop | 4 | 6 |
| Roundhouse | 4 | 6 |
| Total | 36 | 60 |

The salaries paid each six months to apprentices employed in the two courses are as follows:

| A | B |
|---|---|
| 55 cents per hr. | 30 cents per hr. |
| 55 cents per hr. | 32 cents per hr. |
| 58 cents per hr. | 34 cents per hr. |
| 58 cents per hr. | 36 cents per hr. |
| 61 cents per hr. | 38 cents per hr. |
| 61 cents per hr. | 40 cents per hr. |
| .......... | 42 cents per hr. |
| .......... | 44 cents per hr. |
| .......... | 46 cents per hr. |
| .......... | 48 cents per hr. |

The purpose of these courses is to promote graduates of either course to positions of responsibility as openings occur and the individual qualifies for the position. At the present time, this road has seven graduates, two of whom are now serving as enginehouse foremen and five are awaiting promotion. The management pursues the policy that some men are especially adapted to certain lines of work and would be failures in others. It endeavors to place men where they are best suited, both from the standpoint of the company and for themselves.

## RAILROAD "Q"

The special apprentice course on this road is under the direct supervision of the shop superintendent and master mechanic and is directed by the superintendent of motive power. The duration of the apprenticeship is three years. The special apprentice receives 50 cents per hour at the start with an increase of 2 cents per hour every six months. There is no definitely outlined course.

## RAILROAD "R"

The special apprentice course on this road is under the supervision of the master mechanic. The course has not definitely been outlined but is under the direction of the superintendent of machinery. The duration of the apprenticeship is three years. The rates of pay for the special apprentice is not less than that for helper apprentices for whom the rate is 51 cents per hour.

## RAILROAD "S"

Special apprentices employed by this road must be graduates in railway mechanical engineering from a recognized technical university. Each special apprentice attends the regular apprentice schools three hours a week where they study locomotive and car design, thermodynamics relative to locomotive boiler and steam distribution, standard practice and work of a special nature. They are also required to submit a report each month on subjects such as the following: Scheduling, track stresses, locomotive boosters, feedwater heaters, superheaters, valve gears, etc. The following shows the time spent by the special apprentice on various machines and in various departments.

| | |
|---|---|
| Drill press | 1 mo. |
| Shaper | 1 mo. |
| Frames and cylinders | 2 mo. |
| Bolt lathes | 3 mo. |
| Engine lathes | 3 mo. |
| Boring mill | 2 mo. |
| Planers | 2 mo. |
| Cabs and steam pipes | 2 mo. |
| Guides | 1 mo. |
| Shoes and wedges | 2 mo. |
| Air room | 2 mo. |
| Tool room (manufacture) | 1 mo. |
| Motion bench | 1 mo. |
| Valve gang | 2 mo. |
| Boiler shop | 2 mo. |
| Electrical shop | 1 mo. |
| Enginehouse | 3 mo. |
| Freight-car shop | 2 mo. |
| Engine inspector | 1 mo. |
| Air instruction car | 2 mo. |
| Total | 36 mo. |

The following are the salaries paid special apprentices for each six months.

| | |
|---|---|
| First six months | 49 cents |
| Second six months | $51^1/_2$ cents |
| Third six months | 55 cents |
| Fourth six months | $57^1/_2$ cents |
| Fifth six months | 60 cents |
| Sixth six months | $62^1/_2$ cents |

The school schedule for special apprentices on this road is outlined in such a way as to encourage special apprentices to read and study on such subjects as railway economics, locomotive design, car design, locomotive and car performance, combustion, locomotive and car appliances, labor turnover, foremanship, conservation of fuel, materials, etc. The history of transportation, railway organization and finance, relations between various railway departments, locomotive testing and the testing of materials and devices are also included in a recommended course of study for special apprentices.

At the present time this railroad has four special apprentices on its lines and have graduated none since the organization of its present training system. It is greatly interested, however, in this venture and what it has accomplished so far, the road reports, is indicative of some very fine results.

## RAILROAD "T"

Applicants for special apprenticeship on this road must be graduates of colleges of recognized standing in mechanical engineering

or may be first employed during the summer months on the completion of two years of collegiate work in the course mentioned. In the latter case, employment is contingent upon the special apprentice regularly completing his collegiate work.

Special apprentices are not required to attend the regular apprentice school and do the regular assignment of outside work. During their apprenticeship, however, special apprentices are given from time to time outside work such as studies of A.R.A. rules, safety appliance rules, Federal locomotive inspection rules, etc. However, a study is now being made with a view toward drawing up a required course of outside study and reading. This has not been completed but will, in all probability, be based on the following subjects and books: The Railroad Standard Practice Folio; The Railroads Safety First Manual; A.R.A. Rules of Interchange; A.R.A. Safety Appliance Rules; U. S. Government Locomotive Inspection Rules; Locomotive Cyclopedia; Car Builders Cyclopedia; The Locomotive Up-to-date, by Chas. L. McShane; Railroad Freight Transportation, by L. F. Loree and work in a regular apprentice school studying questions on all phases of shop work.

The library of the apprentice school is quite complete with books containing shop administration, railroad accounting, locomotive and car design and repair, etc. Special apprentices are encouraged to make use of the library. Special apprenticeship is based on four periods of 1160 hrs. each with the rates of pay as follows:

| | |
|---|---|
| First period | 50 cents per hr. |
| Second period | 55 cents per hr. |
| Third period | 60 cents per hr. |
| Fourth period | 65 cents per hr. |

The routing of special apprentices to the shop does not follow a regular schedule in sequence. Freight car work may precede boiler shop work but when an apprentice is assigned to one shop, he must complete that before going to another. For example, an apprentice half-way through his freight-car work would not be sent to the engine-house and then back to the freight repair yard. The job assignments of special apprentices are as follows:

Job Assignments

First Year

| | | |
|---|---|---|
| Machines and benches | | 145 days |
| Planer | 12 days | |
| Boring mill | 12 days | |
| Shaper | 10 days | |
| Lathes | 40 days | |
| Rod bench | 10 days | |
| Link bench | 12 days | |
| Lubricators, injectors, etc. | 14 days | |
| Tool room | 25 days | |
| Power plant | 10 days | |
| Erecting floor | | 145 days |
| Shoes and wedges | 14 days | |
| Cylinders and frames | 16 days | |
| Guides and pistons | 13 days | |
| Driving boxes | 14 days | |
| Valves | 48 days | |
| Wheel gang | 16 days | |
| Boiler mountings | 14 days | |
| Special work | 10 days | |

Second Year

| | | |
|---|---|---|
| Gas and electric welding | | 24 days |
| Roundhouse | | 74 days |
| General helping | 20 days | |
| Running work | 30 days | |
| Air and machinery inspection | 24 days | |
| Boiler shop | | 86 days |
| Flues and tubes | 22 days | |
| Ash pan and grates | 16 days | |
| Layout bench | 12 days | |
| Firebox and boiler shell | 36 days | |
| Freight car shop | | 72 days |
| Trucks, couplers, draft gears | 12 days | |
| Wood body work | 35 days | |
| Steel work | 24 days | |
| Riding engines with traveling engineers | | 14 days |
| Special work | | 20 days |

This railroad reports that seniority plays a comparatively little part in the selection of men for minor supervisory positions. Experience and superiority take preference. A special apprentice course takes but two years and it does not expect a graduate to be able to assume a major supervisory position immediately upon graduation. In order to take care of graduate special apprentices, plans have been approved to create positions to be known as mechanical assistants who report to the superintendent of machinery. As mechanical assistants they will be used as "pinch hitters" where-ever additional help is needed for short periods, such as on the dynamometer car, in the mechanical engineer's office, test department or filling supervisory positions temporarily. Mechanical assistants will also be assigned to special work and investigations by the superintendent of machinery. This position will pay $175 per month. The management believes that this method will be of particular benefit to the special apprentices as they will profit by the association and supervision of officials and will give him considerable additional experience. It is intended that graduate special apprentices will work as mechanical assistants until there is an opening which the management believes the individual is capable of filling.

## RAILROAD "U"

The special apprentice employed on this railroad must have completed a technical course along mechanical lines at a recognized technical school and must meet the road requirements for the employment of regular mechanical apprentices which are as follows: Age limit of the applicant is between 18 and 26 years. They must pass a physical examination and serve three years of 290 days in each calendar year.

During the special apprentice course they must study the course prescribed by the Railway Educational Bureau, Omaha, Neb., which deals with technical mechanical problems associated with railway mechanical engineers and supervision. Each special apprentice receives training in the various departments in the different classes of work in the various crafts in the maintenance of equipment departments. They are moved from place to place or required to work in any class of work at the discretion of the officer in charge. The rates paid special apprentices during the different periods of their apprenticeship are as follows:

| | |
|---|---|
| First period | 49 cents per hr. |
| Second period | 51 cents per hr. |
| Third period | 53 cents per hr. |
| Fourth period | 55 cents per hr. |
| Fifth period | 57 cents per hr. |
| Sixth period | 59 cents per hr. |

On completion of their course, special apprentices are placed in positions where their past individual performance has indicated their ability and aptitude are best suited. These positions are selected with the primary object of acquiring further experience in railroad work and they are kept in that position until their work demonstrates that they are ready for promotion to some supervisory capacity.

## RAILWAY-SUPPLY COMPANY "V"

The object of this course is to prepare college graduates for work in the engineering department and for mechanical positions in the field when there are openings for such.

This special course is limited to a period of six months and is purely preparatory, the work covered during this time being a study of the design, construction and operation of numerous typical air brake equipments. A typical daily program is as follows:

7:15 to 10:45 A.M.—Study period
10:45 to 11:00 A.M.—Physical exercise
11:00 to 12:00 A.M.—Lecture and discussion
12:45 to 4:45 P.M.—Practical shop work.

A special class room is provided for the study period, during which period standard instruction pamphlets are used as textbooks. A set of questions covering each pamphlet must be answered in writing, which answers are then checked by other students and a final check made by the department head. Errors must be corrected after a discussion and a clear understanding of the question.

During the lecture and discussion hour lantern slides are used, and members of the engineering department and other departments of the organization, give talks to the class on the subject being studied, or other allied subjects which may pertain to the organization of the company. These subjects are of special interest and value to the student in his work later.

In the afternoon practical shop work is done in a place especially assigned for this work, it being impracticable to work in our regular production departments, as all this work is on a piece work basis. The work performed is to secure from the plant unfinished parts comprising the equipment being studied, which parts must be finished and assembled in the same manner in which they would be applied

to locomotives or cars, thereby giving the student practical knowledge of the device as studied, both from a manufacturing, assembling, installation, and operation standpoint.

As a general rule, the man is assigned work, under supervision in the test department, unless he is interested in design work, in which event he is assigned to the drawing room. As minor executive positions in the engineering department or openings in our field organization become available, selection is made of the man who has demonstrated, by his work and attitude, peculiar fitness for the position.

## Discussion

A. G. TRUMBULL.[11] The paper, which has been prepared by the Sub-Committee on Professional Service of the Railroad Division, presents to the young graduate engineer a very fair statement of the opportunities existing for him in the railroad and its allied field, the supply industry. Of necessity, a report of this character must present pertinent facts, leaving to the individual the application of those facts to his own particular problem.

In this age of intense specialization the choice of a field of endeavor is second only to the choice of a vocation, and requires equally serious consideration. Disappointment not infrequently results from a choice dictated by wholly irrelevant circumstances. Unquestionably, the colleges and technical schools can be of great assistance to their graduate engineers in directing them toward a field of effort appropriate to their particular abilities and individual characteristics. Based on personal experience, as well as contact with young engineers entering the railroad field, the writer has been impressed by what has often appeared to have been an unhappy choice, which well-informed advice might have avoided. No one should be as well qualified to give this advice as the responsible heads of engineering colleges. Vocational departments of these colleges, under the sympathetic supervision of well-rounded executives, should prove of advantage alike to industry, to the colleges, and to their graduate engineers.

There are numerous instances in the experience of every executive in which young men are found to be ill adapted to the work which they have undertaken, due frequently to unhappy parental advice. It is perhaps natural to assume that the youthful pride of the family, who is discovered taking the clock apart, is destined to be a mechanical genius, whereas a disinterested opinion would properly classify this as a simple manifestation of the inquisitive instinct. Many unfortunate errors of choice would be avoided by the application of simple principles of analysis. This may be readily understood in its application to railroads as differentiated from other mechanical pursuits. Of necessity, the problems of maintenance have to do with large units of equipment, and there are obvious instances where individuals are unfitted by temperament and inclination for work of this nature. With equal ability they might succeed in the automobile industry and fail on a railroad, even though their talents were applied with equal industry. Assuming, however, that a choice has been appropriately made, there remain in the railroad field several directions in which mechanical training may be applied.

The Army presents an analogy to the railroads, in that it consists of the line and the staff. The higher officers are generally selected from the line, which limits the opportunities for the staff. While this rule is not as inclusive with the railroads as the Army, it is generally applied. The reason for this, in the case of the railroads, is that they are engaged in the transportation business. Matters relating to equipment, whether of design, maintenance, or operation, and those relating to roadway and structures, are collateral to the general function of the industry. It is natural, therefore, that the line of promotion should lie in the direction of the chief function. This is the reason for the fact that so few mechanical officers are found in the higher executive positions of the operating department. It should not be understood that the avenue of promotion to mechanical-department officers is closed, but it is the exceptionally well-grounded and all-around man who becomes a transportation-department officer.

In the mechanical department there are two fields which the graduate engineer may enter. Primarily, the mechanical department is responsible for maintenance of equipment, and it is maintenance which involves the greatest expense in this department. Here there is the same analogy as in the operating department, i.e., promotion is generally through the line, which is concerned with the maintenance, rather than through the staff, which has to do with engineering.

Having selected railroad work as a vocation, it is therefore important that an early decision be reached as to the particular branch to be followed, since, if the young engineer aspires to become the head of the mechanical department, his opportunities or advancement are greater if he selects shop operation in preference to engineering. On the other hand, if his inclinations are for the purely technical aspects of the work, he is likely to find the shop work irksome and insufficiently interesting to warrant the application, industry, and persistence necessary to advancement.

The report wisely refrains from presenting any rules designed to promote success in the railroad or supply fields. The popular newspapers and magazines are filled with interviews and biographies of prominent captains of industry and leaders of business, most of which, through analysis of the habits of the individual, attempt to indicate qualities which have most contributed to the outstanding success of the object of these articles.

It is a fundamental biological fact that the same success in any field would not be attained by two individuals, even under the same conditions, for the reason that their reactions to a given set of circumstances are entirely different; moreover, the circumstances are never duplicated. This raises the important and ever-debatable question as to the influence of opportunity upon success. Our recent president, Mr. Charles M. Schwab, modestly states that opportunity had much to do with his career, and adds that in his opinion there are any number of men who, having had the same opportunities as he, would have been even more successful than he is generally regarded. It may be questioned if this view promotes a hopeful outlook for the obscure engineer of even average ability. Probably he would prefer to regard individual qualities as of greater importance than fortuitous circumstances. It is quite evident, however, that opportunity does have a large influence upon individual careers, and the difficulty in creating those opportunities is, the writer believes increased by the growth of what has come to be termed "Big Business." But the situation in this report is not less favorable with the railroads than elsewhere.

It is interesting, however, to note those qualities which are considered essential to success in different lines of endeavor. For example, one of the supply companies prescribed these qualifications:

1 Ability to handle men
2 Originality of thought
3 Pleasing personality
4 Initiative.

Probably the packing business is as widely separated as any from the railroad or railroad-supply field. It is interesting to note the views of the head of the personnel department of Armour & Company as to the qualities and abilities which weigh in the rating of supervisors. These are:

[11] Chief Mechanical Engineer, Erie R.R. Co., New York, N. Y. Mem. A.S.M.E.

1 Personal qualities
2 Intelligence
3 Physical qualities
4 Leadership
5 Trade knowledge.

The latter are more general in character and offer a reasonable basis for weighing relative individual abilities. There is nothing to indicate how the maximum of these various qualities may be acquired, but they do suggest the advisability, if not the necessity, of frequently looking into the glass to see how one's general characteristics are contributing to these qualities.

Not all can attain the heights of the profession. For most of us, in the maturity of experience, the fancies of youth will yet have neither form nor substance, but there will be satisfaction if the ideals of the profession are maintained. Moreover it is reasonably certain that each individual will have contributed some share to the advancement of engineering and the mechanic arts. With this, too, a reasonable economic return will have been realized.

L. L. Park.[12] In addition to the points already stressed in the report, there is the problem of bringing the "rank and file" in the motive-power and car departments up to the higher demands of modern equipment. With the increased complexity of the equipment comes not only the need for technically trained leadership but for a better informed group of subordinates, trained to meet the more difficult problems arising out of the new railway policies.

To the technically trained man in the railroad field there is presented the opportunity for aiding those in the ranks who have ability for self-development, to prepare themselves for more effective work. Among the ways in which this service might be rendered are the following:

1 The encouraging and directing of study in technical subjects
2 The application of such technical study to the needs of the mechanical departments
3 Aid in acquiring the art of analysis in problems of improvement in locomotive or car parts to determine the probable cause of failure and means of remedy
4 The development of sane ideas in matters of design.

Too often the men who are eligible for advancement in the mechanical departments are poorly equipped for adequately handling technical matters arising out of railroad operation, and there would seem to be a distinct advantage in having in responsible positions men whose training qualifies them to properly aid in building up the "second line of defense" in the maintenance and improvement of mechanical equipment.

[12] American Locomotive Co., Schenectady, N. Y.

R. S. McConnell.[13] This report of the Committee on Professional Service, Railroad Division, is presented as a demonstration of the average experience that may be expected by the mechanical engineer in these industries.

It is the hope of the Committee that graduates in mechanical engineering, when debating the choice of a career, will give thoughtful consideration to the railroads and allied industries, which, it is believed, present opportunities equal to those offered in any other fields.

The value of the mechanical engineer to railroad and supply organizations, and the opportunities afforded him in these fields of endeavor, are receiving more attention today than at any time in the past. That this is the age of engineering is wholly true of these industries, and the services of competent mechanical engineers are in demand in all lines of operation, maintenance, and sales.

Education and training place in the head and hands of the student the tools with which to work, and reveal to him the purposes for which those tools are intended. The use which the worker makes of that which he has been taught determines how far he will go in his chosen career. Unless we make ourselves useful, we cannot expect the world to pay much attention to us.

It is easy to criticize slow progress; so, if progress appears not to conform to preconceived ideas, the reasons for such failures must not be mistaken. That the fault will not be found in a lack of opportunities for advance is quite as true of the railroad and supply industries as of any other activities.

When honorary membership in the Society was recently conferred upon the distinguished French chemist, Prof. Henry le Chatelier, the *A.S.M.E. News* stated that he remarked in his address of acceptance that "the application of common sense to industry is a distinct contribution of the United States to the present era."

Given the appropriate education and training, that statement of Professor le Chatelier's contains the element for successful achievement within the railroad and supply industries as in any other field of activity.

[13] Chief Engineer, Baldwin Locomotive Works, Philadelphia, Pa. Mem. A.S.M.E.

# Can Accident Prevention Be Reduced to a Science?

By THOMAS H. CARROW,[1] PHILADELPHIA, PA.

*The author concludes that accident prevention can be reduced to a science. This conclusion is based on an analysis of the causes of accidents, which shows that not more than ten per cent are due to misadventure and therefore unpreventable, and an analysis of the human factor to which eighty-five per cent of all accidents are attributable. He stresses the need of complete accident records and of educating supervisory responsibility in safety.*

THE WORD "science" as used in this outline is intended to mean specific ways and means that have been or may be successfully used in the prevention of accidents, particularly with respect to injuries sustained by employees engaged in the railroad, construction, manufacturing, or other kinds of business.

### Number and Cost of Accidents

The reason for and the extent of the effort necessary to prevent accidents in any industry as a whole or in any given unit of an industry are determined primarily by the number, result, and cost of accidents and the advantages to be derived from such effort.

The number, result, and cost may be obtained by an analysis of reports of accidents and other records. Cost includes not only payments on account of compensation, claims, and damage to property, but also expenses due to:

1 Interruption and delay in operation
2 Investigation and reports of accidents
3 Loss of good will
4 Disarrangement of working forces and delay to work
5 Cost of breaking in new men (estimated at $50 to $250 per man).

### Advantages of Accident Prevention

The following statements suggest the possible advantages to be derived from the prevention of accidents:

1 Conserves life and limb
2 Effects economy in operation
3 Increases the popularity of the business
4 Makes the business a more attractive investment
5 Is a good advertisement for efficient management
6 Forestalls burdensome legislation
7 Obviates embarrassment of executive officers
8 Minimizes "hazard of employment" as a factor in wages
9 Does not slow up work or production
10 The public ultimately demands a reasonable standard of safety not voluntarily provided.

### Causes of Accidents, and Preventive Measures

Having determined to put the machinery of accident prevention in motion, the next step consists of an analysis of the causes of accidents and a determination of practical preventive measures, the following being a statement of general causes and the percentage of the total number attributable to each cause, and preventive measures which may be amplified to suit specific conditions:

*Physical Conditions*

| Causes of Accidents | | Preventive Measures |
|---|---|---|
| 1 Unsafe design and construction | 5 per cent | 1 Change in design and improved construction |
| 2 Lack of physical safeguards | | 2 Installation of necessary safeguards |
| 3 Defective material and equipment | | 3 Efficient inspection and maintenance |
| 4 Litter in walk-ways, or material unsafely piled or placed | | 4 Good housekeeping |
| 5 Other physical hazards | | 5 Miscellaneous |

*Human Factor and Misadventure*

| | | |
|---|---|---|
| 6 Violation of rules and other forms of negligence | 10 per cent | 6 Proper training, supervision and discipline |
| 7 Carelessness, thoughtlessness, indifference and ignorance | 70 per cent | 7 Safety organization, education, persuasion and cooperation |
| 8 Physical and mental unfitness | 5 per cent | 8 Proper selection and placing of employees first aid and medical attention |
| 9 Misadventure | 10 per cent | 9 Unpreventable |
| Total from all causes | 100 per cent | |

Note: The percentage of accidents due to each cause varies with different kinds of business and with progress in accident prevention.

### The Individual Worker

From the analysis of the causes of accidents it is seen that 85 per cent of all accidents are attributable to the human factor. It is therefore in line with engineering principles to analyze the nature of the genus *Homo* to determine inherent tendencies to accident and the possibility of counteracting these tendencies. An outline for such an analysis follows:

*The Make-Up of a Man*

| Physical | Mental | Moral |
|---|---|---|
| Positive: | Positive: | Positive: |
| Health | Understanding | Appreciation of right |
| Strength | Judgment | Desire to do right |
| Skill | Reason | Dissatisfaction with wrong |
| Quickness of action | Perception | |
| Eyesight | Apprehension | |
| Hearing | | |
| Negative: | Negative: | Negative: |
| Disease | Natural limitations | Indifference |
| Weakness | Forgetfulness | Carelessness |
| Clumsiness | Dullness | Perversity |
| Awkwardness | | Recklessness |
| Laziness | | Don't care |
| Defective eyesight | | Lack of precaution |
| Defective hearing | | |

[1] Superintendent of Safety, The Pennsylvania Railroad Co.

Contributed by the Railroad Division and presented at the Annual Meeting, New York, December 5 to 8, 1927, of The American Society of Mechanical Engineers.

The extent to which the positive side of the individual is developed represents the degree of success achieved in overcoming the effect of the negative side, that is, the tendency toward accident. Some individuals pass a whole lifetime without serious injury, while others frequently sustain injury, as a complete accident record covering a number of years in any business will show.

### Safety Rules

In every line of work rules are necessary, accident prevention being no exception. Safety rules to be effective must cover both *prohibitions* and *requirements*. Employees in each line of work must be prohibited from doing "things" which may cause accidents, and they must be required to do the "things" that are necessary to insure safety. A report of a preventable accident is record of failure in the performance of duty, either on the part of the man injured, his supervisor, or both. It follows, therefore, that the formulation and enforcement of safety rules suitable to each business is a necessary preventive measure. The safety rules for each industry or business are of necessity peculiar to that industry or business, and should specify the "things" that are prohibited and those that are required.

Violations of prohibitory rules are easily detected. Generally speaking, however, the requirement rules have not been fully developed, and supervisory forces are therefore not educated to enforce them. They are, nevertheless, the more important of the two.

### Accident Record

It is a fact that some accidents are beyond the control of both men and management, while in many instances it is impossible to determine whether the responsibility does or does not lie with the injured. But a cumulative accident record will in time disclose whether an injured man is unduly susceptible to injury in the specific line of work in which he may be engaged. Hence the necessity for complete and continuous accident records.

As bearing on this point, the following accident record of eight men is quoted:

| | |
|---|---|
| Car repairman injured | 3 times in 26 years of service |
| Car repairman injured | 18 times in 9 years of service |
| Machinist injured | 0 times in 31 years of service |
| Machinist injured | 31 times in 23 years of service |
| Freight conductor injured | 1 time in 26 years of service |
| Freight conductor injured | 11 times in 20 years of service |
| Locomotive engineer injured | 0 times in 26 years of service |
| Locomotive engineer injured | 7 times in 33 years of service |

### Educating Supervisory Forces in Safety

If the first step in accident prevention is a matter of supervisory responsibility, which it is generally conceded to be, it is the duty of the management to see that the supervisory forces properly understand how this responsibility should be met, and until a system of accident prevention has been developed along scientific lines, it will not be possible to accomplish maximum results. On the other hand, when accident prevention has been developed along scientific lines, somewhat as suggested in this outline, there is no reason why the management of any business may not expect and determine to a nicety whether or not accidents are being prevented to the fullest extent.

### Reductions in Railroad Accidents

The following are the frequency rates of accidents to railroad employees on duty as reported by the Interstate Commerce Commission, 1923 to date:

| Year | Casualties per million man-hours |
|---|---|
| 1923 | 30.9 |
| 1924 | 27.3 |
| 1925 | 26.1 |
| 1926 | 23.9 |
| 1927 (6 months) | 20.7 |

The progressive improvement indicated, which is very much more impressive with respect to individual railroads than with all railroads taken as a whole, may be attributed to the application of the principles outlined above.

### Cost of Accident Prevention

The cost of accident prevention in its most highly developed form is comparatively low while the returns therefrom are substantial. The experience of a trunk-line railroad, shown below, will prove this:

| Year | Cost of injuries to employees |
|---|---|
| 1923 | $327,656.54 |
| 1924 | 185,297.17 |
| 1925 | 133,057.42 |
| 1926 | 82,470.24 |

### Conclusion

Can accident prevention be reduced to a science? In the light of the foregoing outline, which is based upon exhaustive analysis, the author believes it can.

## Discussion

M. J. T. Conway.[2] Mr. Carrow's paper deals with a timely topic and is of interest not only to the railroad companies but to every industry. He is right in his argument that the supervisory forces must realize their responsibilities as the first step in accident prevention and control. The writer believes that the greatest factor in the cause for accident prevention is the foreman, the first and last man in the supervisory ranks. He is the one man who must be thoroughly sold to the safety-first idea before safety can be efficiently practiced by the rank and file. Indifference on the part of the foreman will surely have its bad effect on those he supervises, and time spent on getting safety thoroughly soaked into the mind of the foreman is the best investment that can be made in an accident-prevention campaign in any industry.

At the plant where the writer is employed, which has the typical hazards of all rolling-mill plants, we have just completed a year's safety campaign put on through the foremen of the plant, and the results have been worth while. The lost-time accidents together with the minor accidents, have been cut down 50 per cent.

The number of trained first-aid men in an organization is fairly indicative of that organization's safety record. It has been the writer's experience that a first-aid man is usually a safety man who preaches safety, a preventive rather than a cure, and the cost of training these men in first-aid work is more than repaid by the cleaner safety records of the organization to which they belong.

William Elmer.[3] The average engineer is fairly familiar with the fact that the railroads of the nation are extremely inter-

[2] Fuel Engineer, Lukens Steel Co., Coatesville, Pa. Mem. A.S.M.E.

[3] Special Engineer, Pennsylvania R.R. Co., Philadelphia, Pa. Mem. A.S.M.E.

ested in the reduction of accidents. They have set a goal for a five-year program of a reduction of 35 per cent in the number of accidents on railroads. They have made remarkable progress toward that goal, and in looking over some statistics it is marvelous to see how some railroads are able to operate with such a small number of accidents, and how far others are behind those ideal performances.

The statistics are usually prepared on the basis of the number of accidents per million man-hours, and some of the railroad systems have reached the point where there are decidedly less than ten casualties per million man-hours. The Union Pacific, for instance, has $3^1/_2$ casualties per million man-hours. The country as a whole averages about 19.

In the train accidents per million locomotive-miles, the Burlington Route and the Great Northern Railroad are both $3^1/_2$ or less, whereas the average for the country is 11. Attention paid to these matters is therefore sure to produce the desired results.

Eliot Sumner.[4] It is possible for a shop force to become over-zealous in the matter of accident records. For instance: A certain shop posted up each month the number of accidents causing loss of time. If an injured employee was attended in the first-aid room and went back to work, no time was lost. An inspection one day disclosed a man reading a newspaper in the locker room. An inquiry developed the information that the man had been injured and was not able to resume his normal duties. However, they thought that he would be in a day or two, so they said: "You come to work anyway, and as soon as you are able to do your regular work we will put you on it." In the meantime he was allowed to read the newspaper, so it was not reported as a lost-time accident and gave a clean record for the month. This shows what may be done with paper figures when they are not carefully policed.

[4] Superintendent of Motive Power, Pennsylvania R.R. Co., New York, N. Y. Mem. A.S.M.E.

The Author. While the case cited by Mr. Sumner is an indication of inefficient management, it is nevertheless a fact that hundreds of men are assigned to other than their regular work, which work they perform efficiently and satisfactorily.

This point is illustrated by an observation made by the general manager of a certain plant to the effect that it was easier for a foreman to send a man home than it was for him to find suitable work for him when he was unable to perform his regular duties. Furthermore, an injured man at some work other than his regular job is better off than when he is loafing.

# High Steam Pressures in Locomotive Cylinders

By LAWFORD H. FRY,[1] BURNHAM, PA.

*In this paper the author attempts an extended survey of the efficiencies obtainable with various steam pressures, and examines the effect of the ratio of expansion on the efficiency. The Rankine cycle, it is pointed out, does not offer a satisfactory basis of comparison for the locomotive; therefore a modification is suggested, known throughout the paper as the "locomotive cycle," and all calculations of the paper are based on this cycle. Changes in boilers to permit operation at high pressures and temperatures are discussed, and it is pointed out that such a boiler would probably require some form of water-tube firebox. Detailed computations and comparisons of theoretical indicator diagrams are made, and the "locomotive cycle" is applied to various admission and release pressures. It is concluded that it is possible to secure a considerable increase in the thermal efficiency of the cylinders by increasing the boiler pressure. The use of three cylinders, one operating on high pressure and two low, makes compounding a very simple matter, permitting the greatest return to be received from the high pressures. For the present, however, it is not felt to be expedient to use boiler pressures much in excess of 450 lb. per sq. in. gage.*

A RECENT paper by Schmidt and Snodgrass[2] gives some information as to experiments which are being made with high steam pressures for locomotives. The theoretical efficiencies obtainable with various pressures are compared briefly, the comparisons being based on the Rankine cycle.

The present paper attempts a somewhat more extended survey of the efficiency obtainable with various steam pressures, and examines the effect of the ratio of expansion on the efficiency. For this purpose the Rankine cycle does not offer a satisfactory basis of comparison, and a modification suggested by the author in discussing the Schmidt and Snodgrass paper is used. This is referred to hereafter as the "locomotive cycle." It assumes that the steam is admitted to the cylinder at constant pressure and temperature, and then, after cut-off, is expanded adiabatically to the release pressure corresponding to the ratio of expansion desired. Release is assumed to take place at the end of the stroke, and the pressure is assumed to fall immediately to the back pressure against which exhaust takes place. The cylinder is assumed to have no clearance.

Fig. 1 illustrates diagrams of this locomotive cycle in comparison with a Rankine-cycle diagram. *ABCDA* is the Rankine diagram for admission at 350 lb. per sq. in., adiabatic expansion to 25 lb. per sq. in., and exhaust at 25 lb. per sq. in. *ABEFDA* is a diagram of the locomotive cycle with admission at 350 lb. per sq. in., adiabatic expansion to a release pressure of 50 lb. per sq. in., and exhaust at 25 lb. per sq. in. *ABNPDA* and *ABQRDA* are locomotive-cycle diagrams with conditions similar to *ABEFDA*, except that the release pressures are respectively 125 and 200 lb. per sq. in. *ABTDA* is a locomotive-cycle diagram with full-stroke cut-off, the release pressure being the same as the admission pressure, 350 lb. per sq. in. Methods of plotting these diagrams, and results obtained by computing and comparing the thermal efficiencies, are given below. Before approaching these problems it is well to consider the values to be assumed for the steam temperature on admission, and for the exhaust pressure.

The present study of high steam pressures is directed to locomotive practice only, and is based on the assumption that no fundamental change in locomotive design is made. It is assumed that if the steam pressure is increased no changes will be made in the locomotive design except those necessary to enable the steam at the higher pressure to be produced safely and to be utilized efficiently. For the locomotive boiler a pressure of 250 lb. per sq. in. is usually taken to be about the maximum that can be carried with the conventional firebox with its sheets supported by staybolts. The use of the higher pressures with which the paper is concerned will require some form of water-tube firebox, but will not force any other vital change. Consequently there seems to be no reason to assume any great change in steam temperatures. At present steam temperatures range normally between 600 and 700 deg. fahr., according to working conditions. In the calculations which follow the steam is assumed to have a temperature of 650 deg. fahr. during admission to the cylinder, irrespective of the pressure.

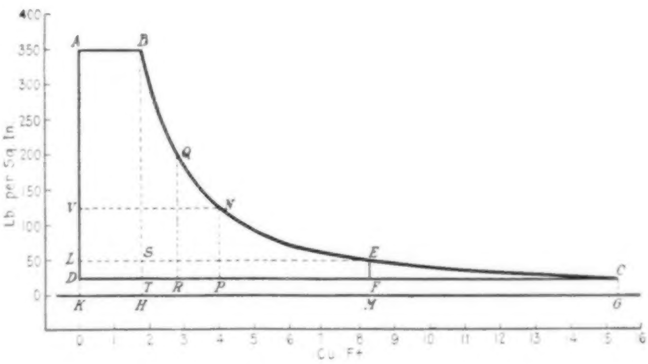


Fig. 1 Theoretical Indicator Diagram for Adiabatic Expansion of 1 Lb. of Steam From 350 Lb. per Sq. In. Absolute and 650 Deg. Fahr.

Another factor stabilized in the locomotive is the minimum exhaust pressure. Exhaust must be made to the atmosphere, and therefore the least back pressure must be higher than atmospheric. In actual practice the exhaust pressure varies between 20 and 50 lb. per sq. in. absolute, according to the rate at which steam is passed through the cylinders. For present purposes the exhaust pressure for the theoretical indicator diagrams which are computed is assumed to be in all cases 25 lb. per sq. in. absolute.

We now take up in detail computation and comparison of theoretical indicator diagrams, and apply the locomotive cycle to various admission and release pressures. In what follows it is convenient to measure all pressures in pounds per square inch absolute. The properties of steam used are taken from Keenan's "Progress Report on the Development of Steam Charts and Tables from the Harvard Experiments."[3] In all of the theoretical indicator diagrams the temperature of the steam on admission is taken as 650 deg. fahr. for all pressures, and the back pressure during exhaust is taken as 25 lb. per sq. in.

Fig. 1 shows the adiabatic expansion of one pound of steam from a pressure of 350 lb. per sq. in. and 650 deg. fahr. Ad-

[1] Metallurgical Engineer, Standard Steel Works Co. Mem. A.S.M.E.

[2] The Use of High Steam Pressure in Locomotives, E. C. Schmidt and J. M. Snodgrass, *Mechanical Engineering*, Mid-November, 1926, p. 1195.

Contributed by the Railroad Division and presented at the Spring Meeting, White Sulphur Springs, W. Va., May 23 to 26, 1927, of The American Society of Mechanical Engineers.

[3] *Mechanical Engineering*, February, 1926, p. 144.

mission of one pound of steam, from *A* to *B* at full pressure and temperature, gives a volume of 1.80 cu. ft. The external work done by the steam during admission is $144 \times 1.80 \times 350$ ft-lb., which is the equivalent of $0.1852 \times 1.80 \times 350 = 117$ B.t.u.

Now the steam tables show that at 350 lb. per sq. in. and 650 deg. fahr. the total heat energy per pound of steam is 1338 B.t.u. Deducting from this the external work as above, leaves 1221 B.t.u. as the internal energy of the steam at cut-off. The curve *BEC* has been determined from the steam tables to show the drop in pressure and increase in volume during expansion. At *C*, with a pressure of 25 lb. per sq. in. absolute, the volume is found to be 15.3 cu. ft., and the quality 0.938 per cent. Under these conditions the steam has a total heat energy of 1102 B.t.u. with an external work value of $0.1852 \times 15.3 \times 25 = 70$ B.t.u., giving an internal energy of 1032 B.t.u. As expansion is assumed adiabatic no heat is received by the steam and all the heat given up during expansion is transformed into work. Therefore the external work done during expansion is $1221 - 1033 = 188$ B.t.u. To complete the cycle the steam must be exhausted. This is assumed to take place at a constant back pressure of 25 lb. per sq. in., giving the line *CD*. The work lost is $0.1852 \times 25 \times 15.3 = 70$ B.t.u. The net work done by the steam during the cycle is therefore as follows:

| | |
|---|---|
| During admission | 117 B.t.u. |
| During expansion | 188 B.t u. |
| Total | 305 B.t.u. |
| Lost during exhaust | 70 B.t.u. |
| Net work of cycle | 235 B.t.u. |

This sequence of operations, admission at constant pressure, adiabatic expansion to a lower pressure, and exhaust at that pressure, constitutes the Rankine cycle. The amount of work developed can be found by a simpler method of calculation than that used above. It is only necessary to note that the steam has on admission a total energy of 1338 B.t.u. and on exhaust 1103 B.t.u., and that as expansion takes place adiabatically, without heat transfer between steam and cylinder, the difference, $1338 - 1103 = 235$ B.t.u., must be the energy transformed into work.

An indicator diagram constructed on the Rankine cycle gives the maximum amount of work which it is theoretically possible to extract from steam working between a given admission and a given exhaust pressure. It has, however, some disadvantages for locomotive work. For example, the steam in a locomotive cylinder is never expanded all the way down to the exhaust pressure. This condition may be approximated with a short cut-off and long expansion, but with a low ratio of expansion the Rankine-cycle diagram is not in any way representative of the actual diagram. With an admission pressure of 350 lb. per sq. in. and expansion to 125 lb. per sq. in. the Rankine-cycle diagram would be *ABNVA*, Fig. 1, which owing to the high exhaust line, would show less work than could be obtained with the lower exhaust line that would be found in practice. A better theoretical representation of practical conditions would be the locomotive-cycle diagram *ABNPDA*.

The work developed in the locomotive cycle is easily calculated by the use of the steam tables. Take for example the diagram *ABEFDA*, representing admission at 350 lb. per sq. in., release at 50 lb. per sq. in., and exhaust at 25 lb. per sq. in. The area of this is *ABELA* with *LEFD* added. The former represents the work done in the Rankine cycle from 350 lb. per sq. in. to 50 lb. per sq. in. As the heat content is 1338 B.t.u. at 350 lb. per sq. in., and 1154 B.t.u. at 50 lb. per sq. in., the area *ABELA* represents $1338 - 1154 = 184$ B.t.u. The area *LEFD* represents the product of the volume *LE*, in this case 8.30 cu. ft., multiplied by *EF*, the difference between the release pressure *EM*, 50 lb. per sq. in., and the exhaust pressure *FM*, 25 lb. per sq. in. Therefore the area *LEFD* represents $0.152 \times 8.30(50 - 25) = 37$ B.t.u. Consequently the total work of the diagram *ABEFDA* is

$$184 + 37 = 221 \text{ B.t.u.}$$

By carrying out similar calculations for various release pressures with admission pressures of 800, 600, 450, 350, and 220 lb. per sq. in., the values given in column 7 of Table 1 are obtained.

TABLE 1 EXPANSION CONDITIONS OF STEAM OF 650 DEG. FAHR. EXPANDED FROM 800, 600, 450, 350, AND 220 LB. PER SQ. IN. TO VARIOUS RELEASE PRESSURES AND THEN EXHAUSTED AT 25 LB. PER SQ. IN.

| 1<br>Admission pressure, lb. per sq. in. | 2<br>Release pressure, lb. per sq. in. | 3<br>Total heat per lb., B.t.u. | 4<br>Quality at release, deg. fahr. superheat | 5<br>Volume at release, cu. ft. | 6<br>Number of expansions | 7<br>Heat transformed to work per lb., B.t.u. | 8<br>Thermal efficiency, per cent |
|---|---|---|---|---|---|---|---|
| 800 | 800 | 1306 | 131.5 | 0.73 | 1.00 | 105 | 8.05 |
| | 700 | 1292 | 113 | 0.81 | 1.11 | 115 | 8.8 |
| | 600 | 1276 | 93 | 0.92 | 1.26 | 128 | 9.8 |
| | 400 | 1235 | 41 | 1.26 | 1.72 | 158 | 12.1 |
| | 250 | 1193 | 0.991 | 1.83 | 2.50 | 189 | 14.5 |
| | 150 | 1152 | 0.952 | 2.86 | 3.92 | 220 | 16.8 |
| | 75 | 1100 | 0.910 | 5.26 | 7.20 | 255 | 19.5 |
| | 50 | 1071 | 0.888 | 7.55 | 10.35 | 270 | 20.7 |
| | 25 | 1024 | 0.855 | 13.9 | 19.1 | 282 | 21.6 |
| 600 | 600 | 1320 | 163.5 | 1.01 | 1.00 | 108 | 8.1 |
| | 400 | 1277 | 105 | 1.38 | 1.37 | 139 | 10.5 |
| | 250 | 1230 | 45 | 1.99 | 1.97 | 173 | 13.1 |
| | 150 | 1186 | 0.992 | 2.98 | 2.95 | 203 | 15.4 |
| | 75 | 1131 | 0.945 | 5.46 | 5.40 | 240 | 18.2 |
| | 50 | 1101 | 0.921 | 7.85 | 7.78 | 255 | 19.3 |
| | 25 | 1052 | 0.885 | 14.4 | 14.3 | 268 | 20.3 |
| 450 | 450 | 1331 | 193.5 | 1.38 | 1.00 | 108 | 8.1 |
| | 300 | 1286 | 133 | 1.89 | 1.37 | 141 | 10.6 |
| | 200 | 1246 | 78 | 2.58 | 1.87 | 168 | 12.6 |
| | 100 | 1184 | 0.997 | 4.40 | 3.18 | 208 | 15.6 |
| | 75 | 1161 | 0.976 | 5.65 | 4.10 | 222 | 16.7 |
| | 50 | 1130 | 0.953 | 8.10 | 5.85 | 238 | 17.9 |
| | 25 | 1080 | 0.915 | 14.9 | 10.8 | 251 | 18.9 |
| 350 | 350 | 1338 | 218 | 1.80 | 1.00 | 109 | 8.1 |
| | 250 | 1298 | 163 | 2.33 | 1.31 | 137 | 10.2 |
| | 175 | 1262 | 113 | 3.07 | 1.70 | 161 | 12.0 |
| | 125 | 1231 | 70 | 3.99 | 2.21 | 181 | 13.5 |
| | 75 | 1186 | 9 | 5.89 | 3.26 | 206 | 15.4 |
| | 50 | 1154 | 0.978 | 8.30 | 4.60 | 222 | 16.6 |
| | 25 | 1103 | 0.940 | 15.3 | 8.49 | 235 | 17.5 |
| 220 | 220 | 1346 | 260 | 2.92 | 1.00 | 106 | 7.9 |
| | 175 | 1319 | 221 | 3.49 | 1.20 | 124 | 9.2 |
| | 125 | 1284 | 170 | 4.52 | 1.55 | 146 | 10.9 |
| | 75 | 1232 | 95 | 6.67 | 2.29 | 176 | 13.1 |
| | 50 | 1197 | 45 | 9.10 | 3.12 | 191 | 14.2 |
| | 25 | 1143 | 0.981 | 16.0 | 5.48 | 203 | 15.1 |

This table consists of five panels, one for each of the admission pressures considered. Column 2 shows the various release pressures to which expansion from the admission pressure is supposed to be carried. Columns 3, 4, and 5 show respectively the total heat, the quality, and the volume of the steam after expansion to the release pressure. Column 6 gives the number of expansions, that is, the volume at release divided by the volume at the end of admission. Column 7 gives the amount of heat transformed into work in the locomotive cycle, that is, expansion to the release pressure and exhaust at 25 lb. per sq. in., while column 8 gives the thermal efficiency of the cycle, that is, the heat transformed into work expressed as a percentage of the total heat energy in the steam on admission.

The figures in Table 1 show the effect of admission pressure and ratio of expansion on the thermal efficiency of the steam in the cylinders. For the first line in each panel the release pressure is the same as the admission pressure, so that there is no expansion, a rectangular full-stroke diagram, as *ABTDA* in Fig. 1, being obtained. Under these conditions the work done is the external work of the steam entering the cylinder less the work lost by exhausting against the back pressure of 25 lb. per sq. in. It will be seen that with this full-stroke cut-off the admission pressure has very little effect on the work done per pound of steam or on the thermal efficiency. The range is only from 105 to 109 B.t.u. per lb. of steam and from 7.9 to 8.1 per cent thermal effi-

ciency. Increase of the ratio of expansion gives an increase in efficiency which is more rapid with the higher admission pressures.

This is clearly shown in Fig. 2, in which the computed thermal efficiency of the cylinders is plotted against the ratio of expansion for each of the five admission pressures. Up to two expansions there is little perceptible difference in efficiency for pressures between 220 and 800 lb. per sq. in. Above this point the efficiency rises faster with the higher pressures than with 220 lb. per sq. in., but nearly 3 expansions are reached before the difference between 350 and 800 lb. per sq. in. is noticeable.

The curves for each pressure are carried up to the degree of expansion at which the pressure is reduced to 25 lb. per sq. in.

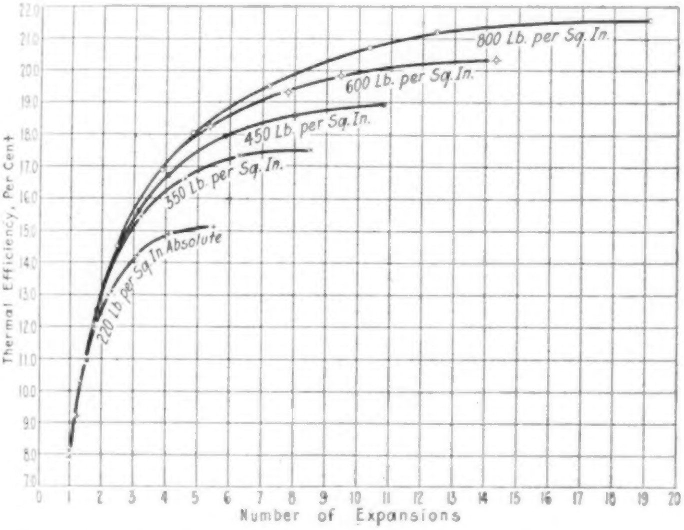


FIG. 2 RELATION BETWEEN CYLINDER EFFICIENCY AND EXPANSION FOR VARIOUS STEAM PRESSURES

(In all cases: Admission temperature, 650 deg. fahr.; exhaust pressure, 25 lb. per sq. in.)

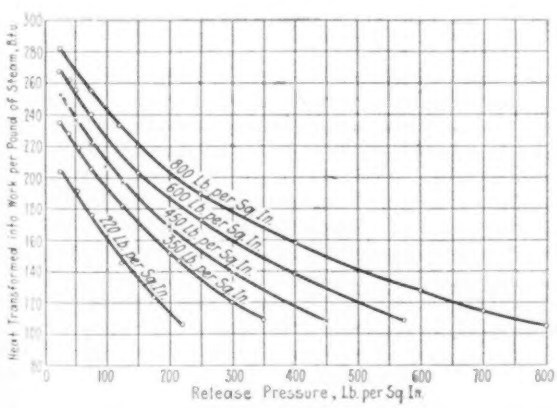


FIG. 3 THEORETICAL DIAGRAMS FOR VARIOUS STEAM PRESSURES, ADIABATIC EXPANSION

(Admission temperature, 650 deg. fahr.; release pressure, 50 lb. per sq. in.; exhaust pressure, 25 lb. per sq. in.)

This is of course a greater expansion than is usually attainable in practice. If the steam conditions only are considered, and the details of cylinders and valve motions required for high expansion are neglected for the present, it may be taken as possible to expand the steam down to 50 lb. per sq. in. and then to release and expand at 25 lb. per sq. in. Under these conditions the figures shown in Table 2 are obtained. To release at 50 lb. per sq. in., 3.12 expansions are required from 220 lb. per sq. in., 4.6 expansions from 350 lb. per sq. in., and so up to 10.35 expansions for 800 lb. per sq. in.

The thermal efficiency in each case is shown in column 6. The values rise from 14.2 per cent with 220 lb. per sq. in. to 17.9 per cent with 450 lb. per sq. in., and 20.7 per cent with 800 lb. per sq. in. These three values bear to each other, as shown in column 7, the relation of 100, 126, 146. That is to say, a rise of pressure of 230 lb. from 220 to 450 lb. per sq. in. raises the efficiency by 26 per cent of its value, while a further rise of 350 lb. from 450 to 800 lb. per sq. in. only adds another 20 per cent. That is to say, the higher the steam pressure the less it is possible to gain by a still further increase. The law of diminishing returns comes into operation. This statement is based only on theoretical thermodynamic considerations and does not take into account that as the pressure is increased the expansion must be

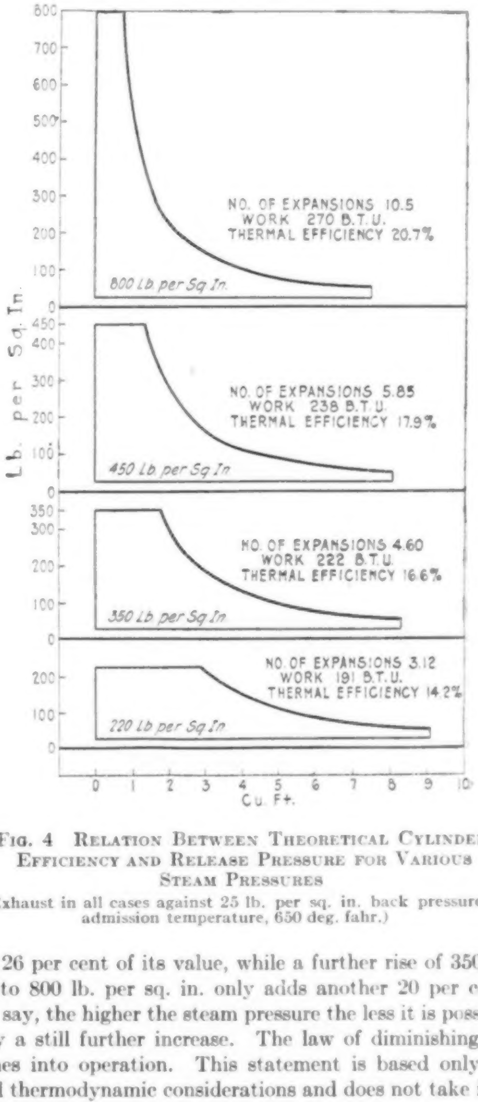


FIG. 4 RELATION BETWEEN THEORETICAL CYLINDER EFFICIENCY AND RELEASE PRESSURE FOR VARIOUS STEAM PRESSURES

(Exhaust in all cases against 25 lb. per sq. in. back pressure; admission temperature, 650 deg. fahr.)

TABLE 2 EFFECT OF EXPANDING ONE POUND OF STEAM ADIABATICALLY FROM VARIOUS PRESSURES

Admission temperature............650 deg. fahr.
Release pressure.................. 50 lb. per sq. in.
Exhaust pressure................. 25 lb. per sq. in.

| 1<br>Admission pressure, lb. per sq. in. | 2<br>Volume at Cut-off, cu. ft. | 3<br>Volume at Release, cu. ft. | 4<br>Number of expansions | 5<br>Heat transformed to work, B.t.u. per lb. | 6<br>Thermal efficiency, per cent | 7<br>Relative efficiencies | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| 800 | 0.73 | 7.55 | 10.35 | 270 | 20.7 | 146 | 125 | 116 |
| 600 | 1.01 | 7.85 | 7.78 | 255 | 19.3 | 136 | 116 | 108 |
| 450 | 1.38 | 8.10 | 5.85 | 238 | 17.9 | 126 | 108 | 100 |
| 350 | 1.80 | 8.30 | 4.60 | 222 | 16.6 | 117 | 100 | ... |
| 220 | 2.92 | 9.10 | 3.12 | 191 | 14.2 | 100 | ... | ... |

lengthened, which will eventually introduce mechanical difficulties with cylinders and valve motion. In addition, each increase in boiler pressure tends to increase the boiler weight and to complicate the design. Taking all these matters into consideration, it appears probable that for the present it will be found that the most economical pressure for construction, maintenance, and operation will be found not to exceed 500 lb. per sq. in.

In order to help to visualize the effect of high admission pressures, diagrams corresponding to the conditions of Table 2 are plotted in Fig. 3 for 220, 350, 450, and 800 lb. per sq. in. In Fig. 4 data from Table 1 are plotted to show for the various admission pressures how the work developed per pound of steam in the locomotive cycle varies with the release pressure.

So far we have dealt with the theoretical expansion of the steam under ideal conditions. In Figs. 6 and 7 the diagram of the ideal locomotive cycle is compared with indicator diagrams taken from an actual locomotive. Fig. 5 reproduces indicator diagrams taken from a three-cylinder compound locomotive operating with a boiler pressure of 350 lb. per sq. in. gage. The three cylinders all have the same dimensions, 27 in. diameter by 32 in. stroke, and are compounded with one cylinder as high-pressure and the other two as low-pressure.

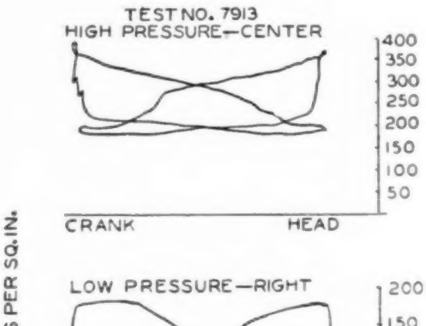


Fig. 5 Actual Indicator Diagrams for Locomotive 60,000 Having One High-Pressure Cylinder and Two Low-Pressure Cylinders

(Steam in branch pipes, 333 lb. per sq. in., 634 deg. fahr.; steam per i.hp-hr., 14.2 lb.)

The low-pressure volume is therefore twice that of the high. The broken-line diagram in Fig. 6 represents the high- and low-pressure cards with the effect of the clearance steam eliminated, and with the low-pressure card drawn to a double scale horizontally. Around this is drawn in full lines the theoretical indicator diagram for the locomotive cycle with expansion to 50 lb. per sq. in. The shaded area between the actual and theoretical cards represents losses by heat transfer between steam and cylinder and by friction in the ports. It will be noted that during admission there is a drop of pressure, but that before release takes place the expansion line comes out to coincide very nearly with the theoretical line representing adiabatic expansion.

This shows that of the heat given up by the steam to the cylinder during admission a large part is returned to the steam

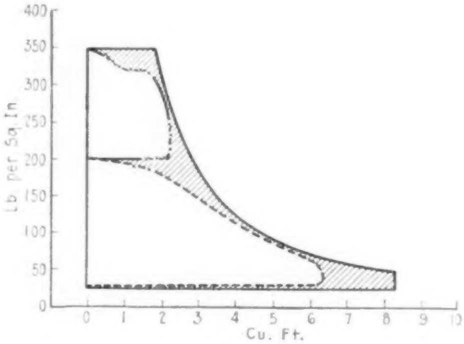


Fig. 6 Adiabatic Expansion of Steam From 350 Lb. per Sq. In., 650 Deg. Fahr., Compared With Actual Cards From Locomotive 60,000—Effect of Clearance Steam Eliminated

(Work per pound of steam: Theoretical, 222 B.t.u.; actual, 174 B.t.u. = 78.5 per cent.)

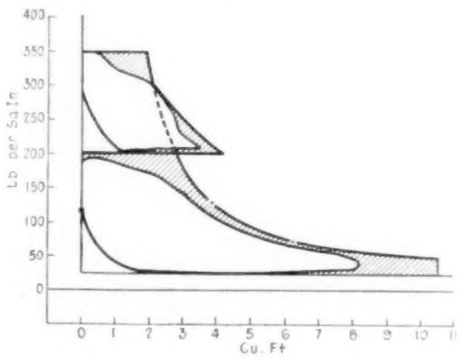


Fig. 7 Adiabatic Expansion of Steam From 350 Lb. per Sq. In. and 650 Deg. Fahr., Compared With Actual Cards From Locomotive 60,000—Effect of Clearance Steam Included

during expansion, so that the actual pressure-volume curve does not drop so rapidly as does the adiabatic curve. The measured steam consumption during the test was 14.2 lb. per i.hp-hr., which corresponds to 174 B.t.u. transformed into work per pound of steam. The theoretical diagram shows 222 B.t.u. transformed per pound, so that the actual area is 78.5 per cent of the theoretical area. The actual ratio of expansion is from 1.8 cu. ft. to 6.4 cu. ft., or 3.6 expansions as against 4.6 expansions in the theoretical locomotive cycle.

Fig. 7 is similar to Fig. 6, except that here the effect of the clearance steam is shown. This shows that in order to provide for 3.6 expansions of the working steam the cylinder volume at the end of the stroke has to be 8.3 cu. ft. That is, the clearance steam makes it necessary to have 30 per cent more cylinder volume than is called for by the theoretical diagrams previously discussed. Consequently, to obtain high efficiency with the higher pressures it will be necessary to use even shorter cut-offs than are indicated by Tables 1 and 2.

## Conclusions

The pressure of 220 lb. per sq. in. absolute used in the calculations corresponds to a boiler pressure of 205 lb. per sq. in. gage. It is evidently possible to secure a considerable increase in the thermal efficiency of the cylinders by increasing the boiler pressure. To secure the full possible increase in efficiency the ratio

of expansion must be increased. This can be done by the use of a special valve motion or compound cylinders, or both. The use of three cylinders makes compounding a very simple matter, and results obtained in practice are very satisfactory. Probably when everything is considered, construction, maintenance, and operation, it will be found inexpedient for the present to use boiler pressures much over 450 lb. per sq. in. gage.

## Discussion

R. Eksergian.[4] The locomotive cycle used by the author approximates an actual cycle; however, actual performances require the use of a cycle factor, which must take care of the equivalent ratio of expansion with a given clearance volume, the cooling, or condensation, effect of the steam during admission in the clearance space, wire drawing and throttling, and the corresponding decrease of availability, the reheating factor which modifies the expansion curve from an adiabatic, the proper compression and its effect on the card, etc.

Therefore, in the same degree of precision to analyze the advantage of raising the pressure and increasing the expansion ratio, careful consideration should also be given to the modification of the cycle factor, which in general can be shown to appreciably decrease with increased pressure and high expansion ratios. The factor, of course, would be different, depending upon whether the steam expanded in a single cylinder or was compounded in two cylinders.

The author has pointed out certain advantages in compounding; that is, the expansion in two cylinders rather than one. It is interesting to compare such expansions.

With simple cylinders, with increasing expansion ratios the cut-off necessarily must be reduced until a condition is reached where the percentage of clearance volume to cut-off volume becomes so large that the loss due to cooling during admission offsets the gain due to expansion. Thus we become definitely limited to given expansion ratios with simple cylinders. The expansion ratio being at best relatively small for any ideal cycle, the clearance volume itself has, therefore, a marked effect on the ratio of expansion. A further disadvantage of single-cylinder expansion is the abnormal ratio of peak to mean piston load, if advantage is to be taken of better expansion ratios, which necessarily must go with increase of pressure at low speeds. This, therefore, requires heavier machinery at the expense of a smaller boiler, with poorer counterbalance conditions.

Compounding offers advantages in the use of greater expansion ratios which are needed to take care of the higher pressures. An outstanding advantage is the greater range of economical performance, because (1) a reasonably good expansion ratio can be obtained at low speeds, and (2) the possibility of relatively greater expansion ratios due to the fact that the cooling effect of the clearance space is reduced. The throttling loss is increased over that of a simple cylinder, but the greater gain in better expansion ratio overbalances this.

H. B. Oatley.[5] The question of pressure must go along with the question of steam temperature, and in the most advanced design of high-pressure power plants the use of reheating or intermediate superheating is also carefully considered. It would have been very interesting if Mr. Fry had extended the first and second sections of Table 1 to show the gain by reheating at 200 lb. or 250 lb. pressure.

The practical problem of reheating is, of course, far harder for the locomotive designer with the limited space available than it is for the industrial-plant designer. The Schmidt-Henschel double-pressure locomotive on the German State Railways impresses one with the fact that an attempt has been made to provide what, in reality, is interstage reheating and at the same time to reach some of the economies which are to be found in the use of steam pressures now being utilized in central power stations and modern industrial plants. The locomotive is of more than ordinary interest because of the marked advance toward higher steam pressures, carrying as it does a working pressure of between 850 and 900 lb. per sq. in., and also because of the double-pressure arrangement of the boiler. This method of steam generation has been provided, and reciprocating engines retained, in an effort to obtain a much more economical unit than any steam locomotive thus far used and to do this by means of a construction far less expensive, equally safe and practicable, and more easily maintained than can be had by the use of an internal-combustion or turbine prime power. Comparisons which will be shown include the performance of other locomotives working with what may be termed high steam pressures, which are to be understood as 250 lb. per sq. in. and upward.

The records of this locomotive support the thermal analysis

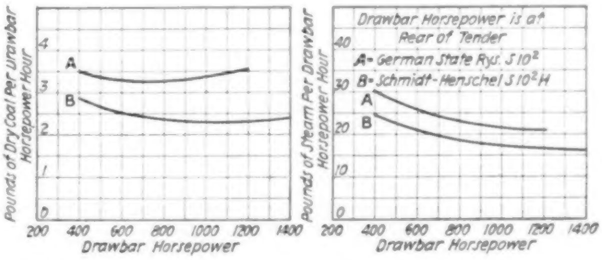


Fig. 8 Water and Fuel Rate Plotted Against Tender Drawbar Horsepower of the German State Railways 4-6-0 Type Before and After Conversion to the Double-Pressure Design

of Mr. Fry. The steam pressures used, however, are above the limits set forth in his paper, but evidently Mr. Fry's limits, as regards pressure, are premised on the use of a single-pressure generator and on the shell of the fire-tube boiler carrying the maximum pressure given to the high-pressure cylinders.

The following data on the Schmidt-Henschel locomotive have been made available through the courtesy of R. P. Wagner, chief of the motive-power division of the Deutsche-Reichsbahn, and S. Hoffman, managing director of the Schmidt'sche Heissdampf Gesellschaft. The tests were run on the Berlin-Magdeburg division of the German State Railways, and dynamometer-car records were used.

Table 3 compares this locomotive with the Pennsylvania I1s class 2-10-0 type locomotive, with the Baldwin experimental 4-10-2 type locomotive No. 60,000, and with the German State S-10-2 class, 4-6-0 type, with normal boiler, of which a large number are in service. The Schmidt-Henschel S-10-2E locomotive was constructed by rebuilding one of the S-10-2 locomotives.

Attention is invited to the fact that in point of size the double-pressure locomotive is, in comparison with the two American-built locomotives, a very small unit, and it may reasonably be expected that had this experimental engine been of a size comparable with the modern American locomotive, there would have been obtained a still lower fuel and water rate per unit of power developed.

Fig. 8 shows the water and fuel rate of the German locomotive plotted against drawbar horsepower before and after its conversion to the double-pressure method of steam generation.

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[5] Vice-President in Charge of Engineering, Superheater Company, New York, N. Y. Mem. A.S.M.E.

The reduction in water and coal consumption through the change in boiler and cylinders is clearly evidenced. In comparing these unit figures it must be kept in mind that the horsepower values are at the rear of the tender.

In Fig. 9 the water rate plotted against drawbar horsepower at the rear of the engine under test-plant conditions is shown. Curve *A* shows the performance of the Pennsylvania I1s class 2-10-0 type locomotive, curve *B* of the Baldwin 4-10-2 type locomotive No. 60,000, and curve *C* of the double-pressure locomotive.

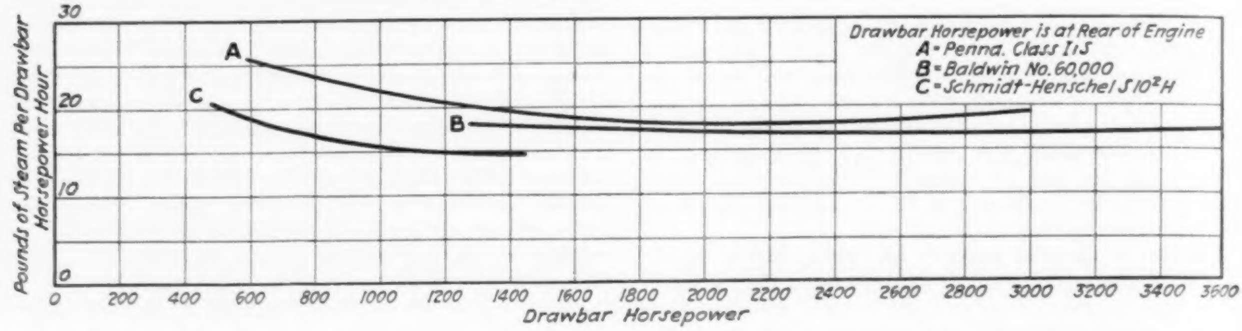


FIG. 9 WATER RATE PLOTTED AGAINST ENGINE DRAWBAR HORSEPOWER FOR THE PENNSYLVANIA I1s, BALDWIN NO. 60,000, AND SCHMIDT-HENSCHEL LOCOMOTIVES

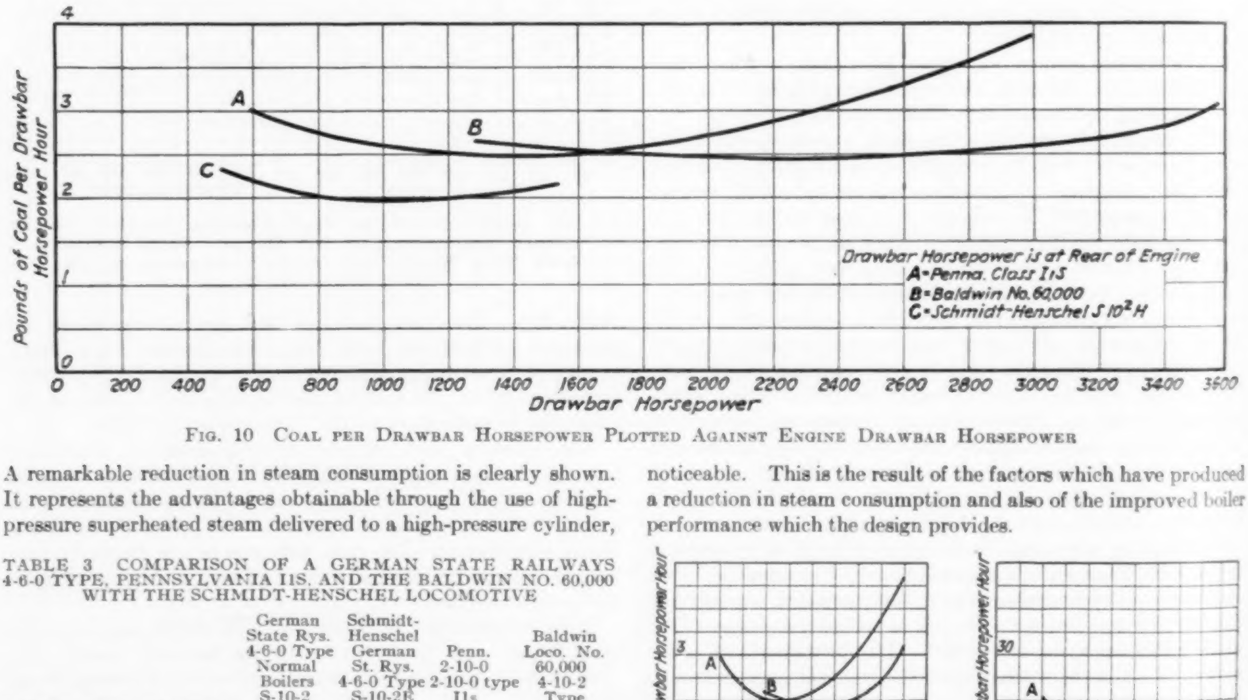


FIG. 10 COAL PER DRAWBAR HORSEPOWER PLOTTED AGAINST ENGINE DRAWBAR HORSEPOWER

A remarkable reduction in steam consumption is clearly shown. It represents the advantages obtainable through the use of high-pressure superheated steam delivered to a high-pressure cylinder,

TABLE 3 COMPARISON OF A GERMAN STATE RAILWAYS 4-6-0 TYPE, PENNSYLVANIA I1S, AND THE BALDWIN NO. 60,000 WITH THE SCHMIDT-HENSCHEL LOCOMOTIVE

| | German State Rys. 4-6-0 Type Normal Boilers S-10-2 | Schmidt-Henschel German St. Rys. 4-6-0 Type S-10-2E | Penn. 2-10-0 2-10-0 type I1s | Baldwin Loco. No. 60,000 4-10-2 Type |
|---|---|---|---|---|
| Working steam pressure, lb. per sq. in. | 199 | 853 high<br>199 low | 250 | 350 |
| Diam. drivers, in. | 77.95 | 77.95 | 62 | 63¹/₂ |
| No. of cylinders | 3 | 3 | 2 | 3 |
| Diam. of cylinders, in. | 19.7 | 1 h.p.-11.4<br>2 l.p.-19.7 | 30¹/₂ | 27 |
| Stroke, in. | 24.8 | 24.8 | 32 | 32 |
| Maximum tractive force, lb. | 31,300* | 33,400 | 90,000 | 82,500 |
| Heating surface, tubes and flues, sq. ft. | 1,494 | 1,258 | 4,044 | 4,447 |
| Heating surface, firebox, sq. ft. | 157.3 | 222† | 290 | 745 |
| Heating surface, total, sq. ft. | 1,651 | 1,480 | 4,334 | 5,192 |
| Superheating surface, sq. ft. | 662 | 856‡ | 1,479 | 1,357 |
| Grate area, sq. ft. | 30.75 | 26.9 | 70.0 | 82.5 |
| Type of superheater | A | 2E | A | A |

* Figured on 85 per cent boiler pressure
† Figured on one-half the surface of water tubes
‡ For both superheaters.

and steam of lower pressure, also superheated, delivered with the steam exhausted by the high-pressure cylinder to the low-pressure cylinders. The low-pressure cylinders, therefore, are working with a much higher temperature than would be possible unless steam of an impracticably high temperature was delivered to the high-pressure cylinder.

Fig. 10 is on the same basis as Fig. 9 and shows coal per drawbar horsepower-hour against drawbar horsepower. The same striking reduction in the fuel consumption per unit of power is noticeable. This is the result of the factors which have produced a reduction in steam consumption and also of the improved boiler performance which the design provides.

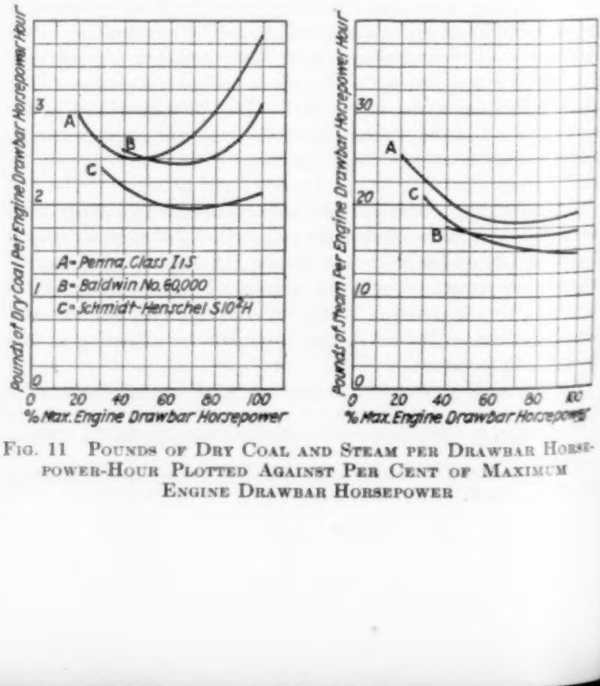


FIG. 11 POUNDS OF DRY COAL AND STEAM PER DRAWBAR HORSEPOWER-HOUR PLOTTED AGAINST PER CENT OF MAXIMUM ENGINE DRAWBAR HORSEPOWER

From the illustrations shown, the fact that the maximum horsepower of these locomotives is not directly comparable because of their difference in size, the relative performance at any given percentage of maximum power is not so clearly evident. To make this a little clearer, Fig. 11 has been prepared showing the steam and dry coal per drawbar horsepower-hour, measured at the engine drawbar, plotted against percentages of maximum locomotive capacity in terms of engine drawbar horsepower. These curves naturally bring the same percentage of power in the same vertical line, and are another way of illustrating the possibilities of further improvement in locomotive economy from a steam and fuel standpoint.

As was to have been expected, a number of difficulties were encountered in this first double-pressure locomotive, but all were of a relatively minor character and have been successfully overcome. Boiler-feeding devices originally applied were not entirely suitable. The means for indicating the water level required some modification. The performance of the locomotive showed that this system of steam generation and use was a perfectly satisfactory, safe, and efficient design. It has been particularly noticeable that there have been no changes necessary in the method of handling the locomotive, and that the engine crews have had no difficulty in adapting themselves to its operation. This is a factor of very great importance when considering new types of steam locomotives where internal-combustion engines or turbines with various power-transmission devices are utilized, and where a very complicated and delicate condensing apparatus has to be used.

The results of these tests fell short of the expected best performance, and some changes are now being made which are confidently expected to provide an additional 10 per cent in fuel economy.

The writer was given the opportunity of making a thorough inspection of this locomotive after the tests had been completed. This inspection confirmed the claims that have been made for the practicability of the Schmidt method of steam generation for locomotive service. The indirect method of steam generation utilized in this locomotive has been used for some time in power plants for stationary service. The writer visited two such power plants where the working steam pressure at the prime movers, which incidentally were reciprocating steam engines, was in excess of 50 atmospheres (735 lb. per sq. in.). Additional confirmation of the satisfactory operation of this type of steam generator was found.

The indirect method of steam generation offers advantages which may in part be described as follows:

1 The high-pressure drum is not in direct contact with the high-temperature gases.

2 The steam generation in the high-pressure drum is uniformly distributed throughout the entire length of the drum. The separation of steam from water, therefore, is more evenly distributed and the so-called geyser action, found in normal boilers, is eliminated. The result is a smaller moisture content in the steam being taken from the pressure boiler.

3 The circulation of water through the indirect heating system is influenced only by the temperature conditions in the firebox. There is no opportunity for an unfavorable circulation caused by other conditions.

4 No stayed surfaces are used either in the indirect heating system or in the high-pressure steam drum. The safety, therefore, of all parts carrying the high pressures is increased.

5 Firing up of a boiler with the indirect heating system can be done much more rapidly and with less stressing of the boiler material than with the usual type of steam generator.

6 The heating surfaces in the high-pressure drum are practically scale free, since its feedwater is taken from the low-pressure boiler where whatever scale-forming material that is introduced remains.

The cleaning of the high-pressure boiler consists simply of washing out any soft sludge which may accumulate. The indirect heating system is a closed circuit and uses water which is scale and corrosion free.

Geo. A. Orrok.[6] The chief difficulty with the high-pressure locomotive lies not in the engine but in the boiler. The magnitude of the pressures depends entirely upon the track gage. The width of the track settles immediately the size of the low-pressure cylinders, and therefore the pressures that can be carried economically.

The boiler problems, on the other hand, become matters of type and construction. The type and manner of construction must be such as to insure satisfactory operation over the usual humps and hollows of the average railway.

This new development of the Schmidt-Henschel locomotive is very interesting because of the absence of many of the difficulties of the high-pressure boiler. This type of boiler is at present occupying the attentions of European designers to a considerable extent. In addition to the work of Messrs. Schmidt and Hartmann, exemplified in the Schmidt-Henschel locomotive, there is the Löffler type of boiler which employs virtually the same idea, that is, of obtaining the high pressures by means of superheated steam so that the vessel containing the high-pressure steam is not subjected to the heat of the furnace. A third type patented by Brown, Boveri and Company eliminates the circulating pump employed in the Löffler type.

The record of 2 lb. of coal consumed per drawbar horsepower-hour is a very excellent performance for a locomotive. This corresponds to approximately $2^3/_4$ lb. per kw-hr. and compares very favorably with the average central-station performance of a few years ago when a consumption of 3.2 lb. of coal per kw-hr. was common. At present the average central station in the United States requires 1.9 lb. of coal per kw-hr., and the best stations run around 0.8 lb.

Considering the fact that locomotives formerly demanded 8 to 9 lb., the record of 2 lb. would seem to approach very nearly the limit on the sizes in use today. It may be possible to drop below that figure, but to obtain the required draft it is necessary to permit some losses.

Lately, the writer has been devoting considerable thought to the length of time our present steam locomotives are going to meet the competition of the new designs. Five different types of turbine locomotives and as many as seven or eight Diesel-engine-powered units have been examined. The former does not seem to be of commercial value at present. The Diesel-engined locomotives appear to be working satisfactorily. Present locomotives of this type, however, are rather small and have been used chiefly for switching service and branch-line work. As far as the writer can see, the future does not hold great promise for this type on our present gage of track. In Russia, where a wider gage is used, it may be possible to build a Diesel locomotive of reasonable size. With the United States standard gage it would be necessary to couple three, four, or possibly five units together to obtain the work required.

It appears that while we may not retain our present design of locomotive, future equipment will of necessity be somewhat similar. Of all experimental engines examined none promises such good results as our own old-fashioned American locomotive type. Three cylinders may be adopted, compounding may follow, and undoubtedly higher pressures than are common today will eventually be employed, but a great deal of work will be

[6] Consulting Engineer, New York, N. Y. Mem. A.S.M.E.

done with the ordinary American type for a great many years.

The Author. It is interesting to find that those discussing the paper are so nearly in agreement with the author. Mr. Oatley's information regarding the Schmidt-Henschel locomotive with double-pressure boiler is a valuable record of the performance of a locomotive that deserves very careful study from any designer who is out for the highest possible cylinder efficiency. Since the paper was written the author has had the privilege of riding on this locomotive and as a result is able to confirm Mr. Oatley's statements. Mechanically the German locomotive seems to do all that its designers expected, and where fuel is expensive it will make a strong claim for consideration. There may be some question, however, as to whether for general service the greater first cost and maintenance will not offset the possible saving in fuel.

# Back Pressure and Cut-Off Adjustment For the Locomotive

By THOS. C. McBRIDE,[1] PHILADELPHIA, PA.

*This subject is discussed from the operating standpoint only. The author presents data showing the indicated horsepower, the steam consumed, and the dry coal fired as functions of the back pressure. He points out that for each locomotive there is a certain back pressure at which maximum power can be obtained at the lowest cost. He advocates a method to determine the best back pressure experimentally, and the use of back-pressure gages for the guidance of the locomotive engineers.*

BACK pressure, as generally understood in connection with the locomotive, may be defined as the pressure of the exhaust steam in the exhaust ports in the cylinder saddle of the locomotive. It has been studied for years in connection with the design of details of the locomotive to the end that it might be reduced to a minimum in the interest of economical operation and increased capacity.

About three years ago, a use for back pressure in the operation of the locomotive was developed. This development followed a demonstration of the fact that the back pressure could be used to indicate the length of cut-off that should be used to obtain maximum power from the locomotive and also to avoid the waste of steam and fuel that would result from the use of an unnecessarily long cut-off. These two viewpoints, that of the designer and that of the operator, should not be confused. It is from the latter standpoint only, presuming that the locomotive has been properly designed, that back pressure and cut-off are considered in this paper.

The first complete demonstration of the principles involved with which the author is familiar is contained in a paper presented by R. W. Retterer before the International Railway Fuel Association at their meeting in May, 1925, and published in the Proceedings of that association. In that paper it was demonstrated that the power that could be obtained from the cylinders of any particular locomotive was limited to a certain definite maximum at any speed high enough to obtain that power, and that when the cut-off was so adjusted that this maximum cylinder power was obtained, the same back pressure was obtained at all speeds. The cylinder power is limited because the further extension of a cut-off already long enough, although it raises the top line of the indicator card and increases the area to that extent, also raises the bottom line of the indicator card and decreases the area to the same or perhaps a slightly greater extent; all because of the increased back pressure due to the greater amount of steam that must pass through the blast nozzle.

Mr. Retterer's paper also described an experiment with a locomotive equipped with a gage in the cab to indicate the the back pressure. The piping connecting this gage to the exhaust ports of the locomotive was provided with a uniflow fitting. This locomotive and a certain train were run six times up a certain grade for a distance of 10,000 ft. The cut-off was kept so adjusted on each run that back pressures of 10, 12, 13, 14, 16, and 20 lb. per sq. in., respectively, were maintained on the back-pressure gage. A maximum speed of 27 miles per hour was obtained on the run with 13 lb. back pressure, and maximum speeds of practically 24 miles per hour were obtained on the runs with 10 and with 20 lb. back pressure. The greatest power must have been obtained with 13 lb. back presssure and less, but about the same power with both 10 and 20 lb. back pressure. The total steam used on the 10,000-ft. run was about the same for 10, 12, and 13 lb. back pressure, but for back pressures above 13 lb. the total steam used increased practically in proportion to the increase in back pressure. From this experiment it must be concluded that any cut-off which resulted in a back pressure of less than 13 lb. did not realize the full possible power of the locomotive, while any cut-off which resulted in a back pressure greater than 13 lb. meant less power developed and more steam consumed—with the chance that the boiler pressure might drop and the train stall.

In order to determine more definitely the relation between back pressure, indicated horsepower, steam consumption, and fuel burned, use has been made of the bulletins published by the Pennsylvania Railroad System from their Locomotive Test Plant at Altoona, Pa. In Fig. 1 these items have been plotted as taken from the bulletin, dated 1915, which reports the test of a P.R.R. standard Mikado, type L-1s locomotive which had the usual standard injector equipment.

Referring first to the solid-line curves marked "injector," it is noted that:

1 The i.hp. reaches a definite maximum of 2750, beyond which no further increase in power is to be expected, and when this maximum is reached the back pressure is 16 lb.

2 The fact that the various points indicating i.hp. fall so close to a smooth curve indicates that maximum power is obtained when the cut-off is so set that a back pressure of 16 lb. is obtained, at least for all the speeds at which tests were made at this power. It might be expected that more power would be developed with the same back pressure at higher speed and shorter cut-off; in fact, the points plotted show a slight tendency in that direction, and in some other plots that had been made this tendency is more pronounced. The points for 100 r.p.m., it is true, are well below the curve, but the points for 80 r.p.m. which have not been plotted fall almost exactly on the curve. Even if it is concluded that, with the same back pressure, more power is developed at higher speed and shorter cut-off, it still remains true that the points plotted indicate that the maximum power for *each* speed is obtained at one and the same back pressure, and the usefulness of back-pressure indication of proper cut-off to obtain maximum power is not lessened.

3 The curves "steam to engine" and "dry coal fired per hour" also show points falling quite close to a smooth curve, and steam and fuel consumption increasing at a rapid rate as the back pressure which represents maximum power is reached.

It is doubted whether locomotives are operated on the road for any very long periods at the excessive rates to which they are forced on the test plant, principally because of the difficulty in maintaining steam pressure. It is noted also that the last 100 i.hp. developed require 7000 lb. of steam and 2400 lb. of coal per hour, and are obtained at an almost prohibitive cost. These two features seem to indicate that, instead of attempting to obtain the outside maximum cylinder power possible through

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the use of a cut-off resulting in 16 lb. back pressure, it might be advisable to use a slightly shorter cut-off, resulting in, say, 13 lb. back pressure, with the assurance that the boiler pressure would be maintained and with the avoidance of the expenditure of so much more fuel to obtain just a little more power. Here, then, the engineer should be instructed to keep the cut-off so adjusted that a back pressure of 13 lb. is obtained whenever maximum power is desired. A shorter cut-off, indicated by a back pressure

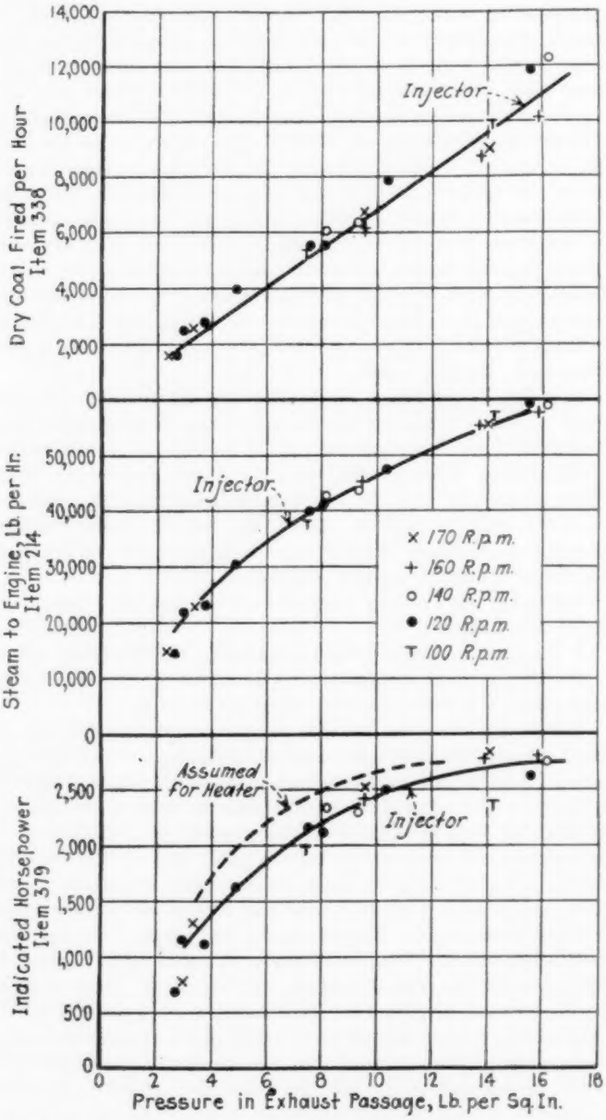



Fig. 1 Data From Pennsylvania Railroad Locomotive Test Plant

(Bulletin No. 28, Pennsylvania Railroad Co. L-1s Mikado Locomotive.)

of less than 13 lb., would not realize the full possible power of the locomotive. A longer cut-off, indicated by a back pressure of more than 13 lb., would not realize any more, but probably somewhat less, power developed. More steam would pass through cylinders, more fuel would be burned and this additional fuel wasted, and with a cut-off much too long the capacity of the boiler might be exceeded and the steam pressure drop.

Question naturally arises as to when or under what operating conditions of the locomotive back pressure can be made useful in its indication of the proper adjustment of the cut-off. There are roughly four different conditions of operation on the road to be considered as concerning the adjustment of the cut-off:

1 *Drifting*, when the length of cut-off is determined by mechanical and not economic conditions.

2 *Light power*, when the cut-off should be as short as smooth operation of the locomotive will permit and the speed controlled by the throttle and the length of cut-off again dictated by mechanical conditions.

3 *Medium power*, when the throttle should be full open and the speed controlled by the adjustment of the cut-off. The length of cut-off is dictated by the speed required, the steam is used economically, and nothing further is needed to assure the use of a cut-off of proper length.

4 *Maximum power and powers approaching the maximum*, when the throttle should be full open and the cut-off only as long as is necessary to secure the maximum cylinder power. It is under this condition alone that the back-pressure gage can be of use as an indication of the best adjustment of the cut-off. Modern conditions have required the operation of locomotives at maximum or near maximum powers a large portion of their time on the road. The back-pressure gage should be of great assistance in meeting this requirement.

Incidental advantages of the back-pressure gage at powers other than maximum have already been noted, but these are generally foreign to the determination of the proper adjustment of the cut-off and the economic operation of the locomotive.

Now that there are over 5000 locomotives equipped with feedwater heaters in service in the United States and Canada, the indications of the back-pressure gage with the feedwater heater in service demand consideration. The same or practically the same length of cut-off is required for the same power developed by the heater locomotive and by the injector locomotive, but the back pressure on the heater locomotive is lower because of the exhaust steam taken by the heater to heat the feedwater. No tests have been made on the test plant and, as far as the author is advised, no tests have been made on the road showing comparable data on heater and injector operation of the same locomotive at powers approaching the maximum for the cylinders. It has therefore been necessary to calculate the relation between back pressure and i.hp. for the heater locomotive. This relation is shown by the dotted curve of Fig. 1. In laying out this dotted curve it was assumed that for the same power developed the back pressure obtained would be that corresponding to 15 per cent less steam than is shown by the "steam to engines" curve, inasmuch as approximately 15 per cent less steam would pass through the blast nozzle of a heater locomotive with water at the temperature of the water used in this particular test-plant test.

It is noted from the curves that the maximum cylinder power of 2750 i.hp. is obtained with the heater locomotive with a cut-off which results in 12 lb. back pressure as compared with 16 lb. back pressure for the injector locomotive, and that this cylinder power could be maintained with the heater locomotive because it requires 8200 lb. of coal burned per hour, whereas the same power could not likely be maintained by the injector locomotive because it requires the burning of approximately 11,000 lb. of coal per hour. Greater sustained maximum power is possible because of the feedwater heater. The back-pressure gage, properly used, offers the same assurance that this greater sustained maximum power will be obtained from the heater locomotive that it presents for the obtaining of maximum power from the injector locomotive.

It is a well-known fact that there is a tendency to operate locomotives by "the sound of the exhaust," this sound at least influencing the engineer's judgment in the adjustment of the

cut-off. If a heater is applied to a locomotive and the locomotive operated with the cut-off so adjusted that the exhaust sounds the same as it sounded previously with the injector, then the back pressure must be the same and, consequently, the same amount of fuel is burned with the heater as with the injector. One result would be obtained with such operation at medium powers of the locomotive and a quite different result at maximum or near-maximum powers. Referring to Fig. 1, it will be noted that at medium powers more power will be developed with the heater, which, with the same tonnage, will appear as increased speed. The same amount of fuel is burned but more power is obtained, and the heater is used to increase the capacity of the locomotive rather than to save fuel. At maximum or near-maximum powers, however, with the same sound of the exhaust and the same fuel burned, the same power would be developed. For example, referring again to Fig. 1, with 14 lb. back pressure, 2700 i.hp. would be developed and 9600 lb. of coal burned, both with the heater and with the injector. The saving in fuel obtained from the heater is cancelled by the unnecessarily large amount of steam supplied to the cylinders due to the use of entirely too long a cut-off with the heater. The back-pressure gage can be used to determine and demonstrate this lower back-pressure necessary with the heater if full advantage is to be taken of the heater.

Since a considerable number of exhaust-steam injectors are in service, an attempt was made to develop the relation between back pressure and power developed with them, but too many assumptions are necessary. These injectors are generally so selected as to size that the ordinary working rates of the locomotive are above their minimum capacity and the maximum capacity of the locomotive is then generally above their maximum capacity. Furthermore, the amount of exhaust steam that can be used by the exhaust-steam injector varies with the capacity at which it is worked, and the amount that is used varies with the adjustments made. The reduction in back pressure with the exhaust-steam injector in service is therefore a variable quantity that would make it difficult to interpret the readings of the back-pressure gage as an indication of cut-off adjustment.

It is evident from all of the above that if back pressure is to be used to secure proper operation of the locomotive as to cut-off, then some method must be developed to determine experimentally the best back pressure, i.e., the back pressure which results from the shortest length of cut-off that will develop the maximum power that can be maintained with each railroad class of locomotive when the speed is high enough to obtain that power. The method most used to date has been that of operation by an expert whose judgment is depended upon to determine the best back pressure. The method used by Mr. Retterer as described in his paper submitted to the International Railway Fuel Association, and briefly in this paper, obtains more exact information. Where a locomotive has been tested on the test plant the best back pressure can be determined by the method suggested in Fig. 1. Where a dynamometer car is available or in use for other purposes, simultaneous readings of the back pressure and drawbar horsepower developed could be plotted and the minimum back pressure, and therefore minimum steam consumption for maximum drawbar horsepower, thus obtained.

By these methods the best operating cut-off is determined for each class of locomotive. The back-pressure gage supplies a permanent record of this best operating cut-off and makes it possible to reproduce it in every-day operation on the road with the assurance that maximum power when required will be immediately obtained, and that without the supply of unnecessary steam and consequent waste of fuel.

The "position of the reverse lever" has been appreciated as a very important factor in the operation, and particularly the economic operation of locomotives. The individual performance of the engine men varies widely both in the handling of the locomotive and in fuel consumption. *Railway Age* of June 19, 1926, reported some tests of individual performance on the Union Pacific Railroad and stated:

> On analyzing the results, it was found that the individual performance of one of these enginemen when compared with the other nine as a group showed a saving in fuel per thousand gross ton-miles of 17 per cent. The tests also showed that in this group of nine enginemen there were individuals falling as much as 30 per cent below the best man. * * * * * * * one or two enginemen were found whose performance was such that it could scarcely be improved, while one individual engineman was found using as high as 45 per cent more fuel per 1000 gross ton-miles than was demonstrated by the test to be necessary.

Such wide variations in individual performance are not at all unusual. Of course, condition of equipment, weather, etc. must be considered, but Mr. Retterer's experiment and Fig. 1 indicate that the individual habit in the adjustment of the cut-off can and must be largely responsible for these very wide variations. The essentials necessary for good cut-off adjustment can scarcely have been appreciated in the past since many locomotives are supplied with reverse-lever quadrants with notches so coarse that it is impossible to make the fine adjustments of the cut-off which have been demonstrated to be necessary. It is evident that something better and more exact than the judgment of the enginemen is needed to indicate the best adjustment of the cut-off in order that this adjustment may be made exactly and quickly. The back-pressure gage properly used should fill this need.

## Discussion

E. S. Pearce.[2] The theoretical soundness of back-pressure regulation as a means of accurate cut-off adjustment has been very definitely established by Mr. McBride.

An investigation of the operation and development of this principle, as carried on for some eight years, might clearly indicate that a full realization of the benefits reasonably to be anticipated cannot be obtained through the medium of back-pressure gages located in the cab to which back-pressure steam is conveyed from the exhaust passages of the cylinders. Conclusively, neither the gage, the cut-off adjusting means, nor the engineman are accurate, dependable or constant.

The regulation of cut-off to any constant back pressure must be done within a total range of $1^1/_2$ lb. of the constant. The indicating means must be free of pulsations, yet it must not lag behind changes in the cylinder exhaust.

Gages subject to pulsations deteriorate rapidly and become inaccurate. Choking the pressure line to protect gages retards transmission of changes with proper rapidity, and therefore adjustments are not in keeping with cylinder exhaust conditions. The gage, under any condition, is inaccurate because of the hydraulic head of condensed steam in the back-pressure pipe. The gage in the cab may be four to eight feet higher than the cylinder. Condensed steam, which exists in a greater or lesser degree, produces a hydraulic head of varying amount, which the cylinder exhaust pressure must sustain, and the gage indicates the differential, not the cylinder exhaust pressure.

The reversing mechanism, for either manual or power operation, generally in use on locomotives has not been designed or applied with the idea of obtaining accuracy of adjustment or positive holding power necessary to produce or maintain cut-off settings of the required fineness.

[2] President, Railway Service & Supply Co., Indianapolis, Ind. Mem. A.S.M.E.

Finally, the engineman, who must provide the additional mental and physical effort over his now customary operation, is quickly aware of the inadequacy of the means provided, and regardless of his belief in and desire to follow the principle of back-pressure regulation of cut-off, he soon gives it up.

In addition, on modern locomotives, under existing conditions of operation, the engineman has not the time constantly to follow such an absorbing duty in addition to those already imposed upon him.

Confronted with these limitations and at the same time appreciative of the ultimate possibilities of practical application of the theory described, there has been developed and put into successful operation a mechanism for installation on the engine, actuated and responsive to back pressure, which without effort on the part of the engineman provides the locomotive with a self-regulating means of adjusting cut-off to constant back pressure. This device is so designed that at will the engineman may set the engine to operate at any one of three back pressures, the purpose of this being to provide for locomotive operation subject to three of the four conditions cited by Mr. McBride.

In operating a locomotive with this device the engineman, for maximum power, turns a lever to that back-pressure index established for maximum capacity. For medium power a pressure lower than the maximum is obtained by the engineman's turning to the equivalent setting, and for light power, a pressure setting less than that for medium.

There are in service in this country a considerable number of locomotives employing the mechanical device above described, which virtually adjust their own cut-off instantly to existing conditions of speed, load, and steam-admission pressure.

Operation of these engines has resulted in very interesting data as to the possible improvement in economy and capacity to be obtained on existing locomotives.

One instance of an operating division has shown that under identical operating conditions, with 93 per cent of the engines equipped to regulate their own cut-off, the 1000 gross ton-miles per hour were increased 30 per cent with practically the same gross tons per train. In this instance the capacity of the engine was utilized in speed.

In another instance, with a locomotive operated with this device over a 30-mile division, having the same train back-hauled for hand-operation test, and all operating conditions identical, a fuel performance with one engineman of 140 pounds of coal per 1000 gross ton-miles, as against 120 for the machine, was obtained. Another similar test showed 118 pounds of coal per 1000 gross ton-miles for the machine as against 132 for hand operation by the engineman. This is an instance of utilizing the machine purely for fuel saving with tonnage, time, and all other conditions being the same.

In some recent tests on another railroad where the same locomotive was operated over the division by various enginemen in hand operation, alternating with machine operation, an average saving in coal of over 20 per cent per 1000 gross ton-miles was shown in favor of the machine.

These economies are not surprising as it is recognized by railroad operating officials that there is easily a difference of 10 to 20 per cent between the performances of their best and their average enginemen, and a greater difference between their best and their poorest. If a machine did no more than operate all locomotives as good as the best engineman, there would be a considerable element of economy.

It must be further recognized that generally in freight service every-day train loadings are not those established by test, or by what the best engineman can handle, but are nearer the tonnage which can be safely taken over the railroad by the poorest engineman.

The following statements were made by A. W. Bruce, Designing Engineer of the American Locomotive Company, before the Western Railroad Club:

> A railroad is nothing more than a commercial manufacturing plant, the only product of which is transportation, and in which the locomotive is the only direct revenue-producing unit.
>
> The writer realizes perfectly the enormous amount of capital represented in motive-power equipment. What other manufacturing industry, however, could be carried on competitively, using continuously machines twenty to twenty-five years old in the manufacture of its product?

Mr. Bruce's statements are very significant, and to them may be added the thought that the locomotive, which is the productive earning unit of the railroad, is still operated, so far as steam utilization is concerned, by manually controlled rule-of-thumb methods. It is not unreasonable to suppose that elimination of the personal equation by mechanical means should be as proportionately economic in this field as it has been in many others.

W. E. Symons.[3] Although ready at any time to defend the modern equipment of the American railroads, particularly our locomotives, the writer is perfectly willing to admit that efficiencies are not as great as they might have been had certain details been given the attention they deserve. One in particular is back pressure on the pistons. There are thousands of locomotives running today with back pressures on the pistons of from 8 to 15 lb. which should be running with less than 6, and some less than 5—around 4. The effect is equivalent to the sticking of brakes, and the resultant loss of power has cost the railroads of this country vast sums of money. This effect can be eliminated and without putting back-pressure gages in the cab. Although they are splendid indicators, why apply some special device at a considerable expense to remedy a thing that we know exists and for which there is a plain, common-sense remedy without these special gages in the cab?

The writer has ridden on a four-cylinder locomotive representative of common European practice, at a speed of 100 kilometers (about 62 miles) per hour. This engine was equipped with a double valve gear so as to permit adjustment of the admission of the steam to the cylinders and also to control the back pressure of the pistons. By a slight change in the valves controlling the exhaust steam from the low-pressure cylinders, and without admitting an ounce more of steam from the boiler, the engine accelerated from 15 to 20 miles in speed. That is a fair indication of what can be done with American locomotives.

A ten-wheel locomotive built by the American Locomotive Company, reputed to have attained a speed of 120 miles per hour, had a back pressure on its pistons of less than 5 pounds. If the pressure had been as great as in the average passenger locomotives in America it would never have made more than 80 miles per hour, and probably less. It is difficult to understand why, with all the ingenuity that has been brought to bear in designing locomotives and purchasing saving devices, that engineers have not applied themselves more diligently and effectively to facilities for regulating the exit of the steam from the cylinders.

A. I. Lipetz.[4] The writer regrets that he cannot agree with Mr. McBride's theory as to back pressure and cut-off adjustments, although it must be admitted that the now popular trend of equipping locomotives with back-pressure gages can be of a practical value in some instances.

[3] Associate Editor, Engineering Publications, Angus Sinclair Publishing Co., New York, N. Y. Mem. A.S.M.E.

[4] Consulting Engineer, American Locomotive Co., Schenectady, N. Y., Non-resident Professor of Locomotive Engineering, Purdue University, Lafayette, Ind. Mem. A.S.M.E.

In order to make clear the remarks which follow, several mass diagrams of results obtained from Altoona tests with the well-known I1s locomotive of the Pennsylvania Railroad will be

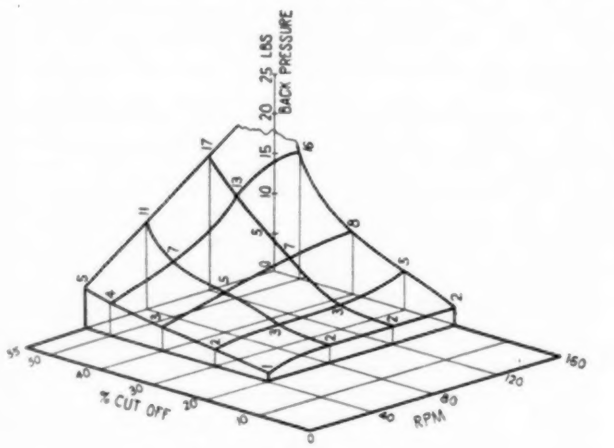



Fig. 2

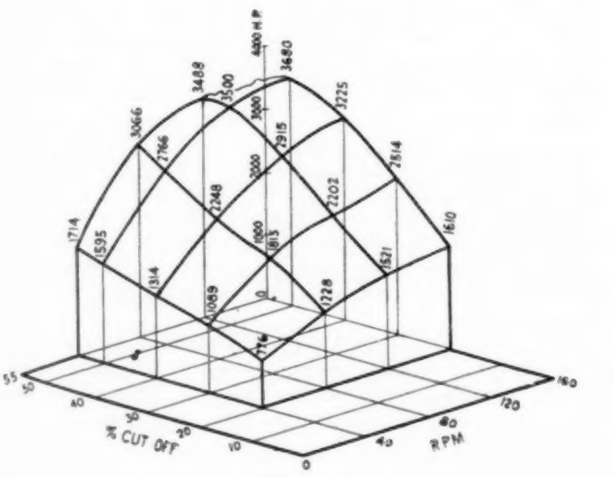



Fig. 3

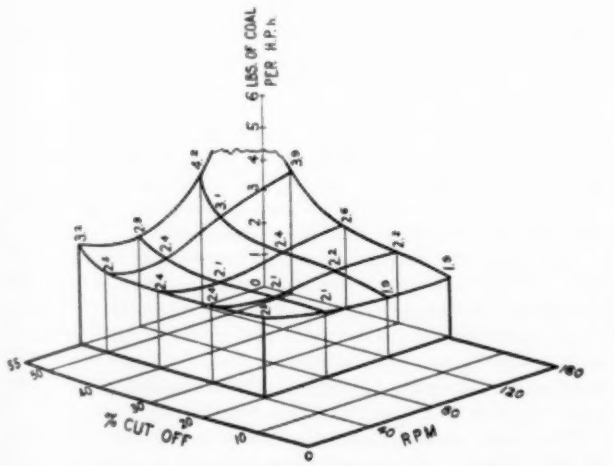



Fig. 4

presented. These tests were chosen for the reason that Mr. McBride refers to them in his paper, although the writer prefers a more modern locomotive than the I1s. The mass diagram of Fig. 2 shows the back pressure as a function of both cut-off in per cent of stroke and speed in revolutions per minute. Fig. 3 gives the indicated horsepower of the locomotive in relation to the same two variables. Fig. 4 shows the fuel consumption in pounds per indicated horsepower-hour. The three mass diagrams refer to full throttle opening. It can be seen that the back pressure goes up slowly with the speed at short cut-offs, and with the cut-off at low speeds, but as both speed and cut-off increase simultaneously the back pressure goes up very rapidly—this resulting in a surface of a more or less hyperboloidal form. As regards the horsepower the variation is reversed. It is more pronounced at low speeds and short cut-offs and drops down as both speed and cut-off go up, resulting in a surface of an ellipsoidal form with a distinct maximum value. The consumption of fuel

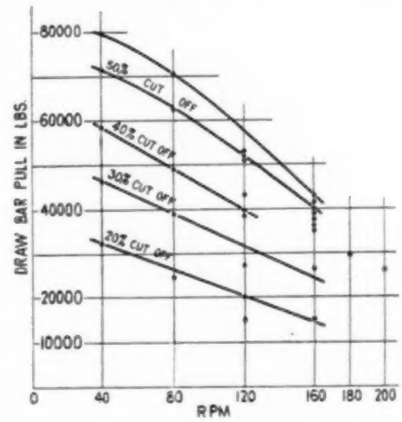



Fig. 5

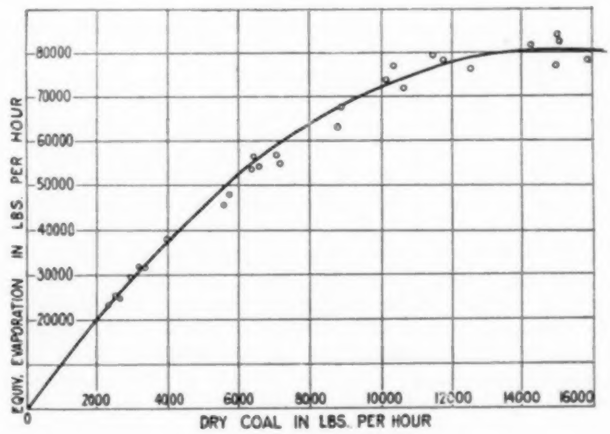



Fig. 6

is more or less uniform when the horsepower is low, but increases rapidly with the increase of output.

Two ordinary charts also are shown which give the variation in drawbar pulls in relation to speed (Fig. 5), and the equivalent evaporation of water as a function of the amount of coal burned in the firebox (Fig. 6). They are taken from Test Bulletin No. 32 of the Pennsylvania Railroad. All the mass diagrams and charts refer to sustained conditions of locomotive performance.

By comparing the figures shown in the mass diagrams it can be seen that in one case an output of 3500 horsepower can be obtained at 50 per cent cut-off and 120 r.p.m.; the back pressure will then be 13 lb. per sq. in. (all pressures above atmosphere). As can be seen from the accompanying chart, the engine under these circumstances will develop a drawbar pull of about 52,000 lb. If the train tonnage and profile are such that this exceeds

the train resistance, the speed of the locomotive will go up, and if it should reach 160 r.p.m., the power developed at the latter speed will be 3680 horsepower and the back pressure will go up to 16 lb. per sq. in.; the fuel consumption also will change from 3.1 to 3.9 lb. of coal per indicated horsepower. Such a performance may not be considered economical, but disregarding for a moment the thermal efficiency of the locomotive, it will be seen that a greater horsepower was obtained at a higher back pressure and, consequently, a back pressure of 16 lb. per sq. in. must be allowed, if such a speed on a grade is required.

On the other hand, suppose that when the engine is developing a drawbar pull of 52,000 lb. with 50 per cent cut-off at 120 r.p.m. the grade changes and the engine driver may wish to retain the speed. If he should attempt to increase the cut-off to 55 per cent, the back pressure will go up from 13 to 17 lb. per sq. in., reaching probably 16 lb. per sq. in. at somewhere between 50 and 55 per cent cut-off. But as can be seen from the mass diagram he can gain nothing from that as the power remains almost constant and, as the tractive effort has gone up, the speed will drop. It can be seen, therefore, that the back pressure is a function of the combination of cut-off and speed, and it cannot be stated that the maximum power is obtained at a constant back pressure for all speeds.

It is true that the back pressure at maximum power varies very little. This is simply due to the fact that when the locomotive approaches its maximum output the possibility of varying speed and cut-off becomes very slight. A locomotive does not develop its maximum power at low speeds no matter how big a cut-off is used. Neither does it develop its maximum power at high speeds with short cut-offs. The engine will therefore most of the time have a back pressure of 3 to 7 lb. per sq. in. Maximum power is obtained only when both long cut-offs and high speeds are used, and consequently the back pressure must be near the maximum and cannot vary greatly. This may lead to an impression that the back pressure is constant at maximum power, but, as has been shown above, it cannot be considered so.

The above-mentioned 16-lb. back pressure permitted burning $3.9 \times 3680 = 14{,}352$ lb. of coal per hr., or, as the grate area of the locomotive is 70 sq. ft., 205 lb. per sq. ft. per hr. Such a rate of firing is very wasteful, and it would be more advisable to reduce it to 100 lb. per sq. ft. per hour, or even less, in order to obtain higher boiler efficiency (see equivalent evaporation chart). Then, if a *maximum* back pressure of 7 lb. per sq. in. is ruled, the engine driver may choose between two combinations—50 per cent at 80 r.p.m., and 40 per cent at 120 r.p.m. The back-pressure gage will give him no indication as to which of these two combinations to use, but an experienced driver will choose in accordance with requirements of traffic—tractive effort and speed. In one case he will get higher drawbar pull; in another, higher speed and power, although the back pressure remains unchanged.

The limitation of back pressure to 7 lb. per sq. in. means in this case only that the tonnage and speed should be such as to require no more than 2915 horsepower. If the train is heavier, or the time table requires higher speed, the driver will have to go to higher back pressures.

This reasoning applies, as stated above, to sustained conditions of locomotive performance. Performances corresponding to those given by the diagrams may go on indefinitely, but it is possible for short periods to overload the locomotive and to make use of a portion of the heat energy stored in the hot water in the boiler. The steam pressure may for a certain period of time remain unchanged, but the water level will drop. For short distances this can be permitted, and then higher cut-offs at higher speeds can be used and still higher back pressures will be obtained without doing any harm to the locomotive. While it is true that this may result in consumptions of fuel of over 4 lb. of coal per i.hp-hr., this will not amount to much if the periods are short, and it may still be more economical for operation over the whole division to overload the locomotive over a short stretch of track. The *constant*-back-pressure theory would do harm in such a case, but the *maximum* pressure indication may be of some practical value. This can be determined only by experience or special tests.

If, however, the engine driver should tax the boiler still heavier, a drop in boiler pressure will take place and the conditions of locomotive performance will become unstable. The drawbar pull will correspondingly drop and the storage capacity of the boiler will soon become exhausted. This should never be attempted in proper handling of a locomotive, but it happens very often when a heavy train is too rapidly accelerated from rest to a high speed, just before a heavy grade, and stalling of the locomotive results. These are the tests which were made by Mr. Retterer to which Mr. McBride refers, and the practical value of his conclusions is that such manipulations should not be permitted, and in order to avoid them back-pressure gages should be used. This is quite a different matter and cannot be corroborated by referring to Altoona tests which were made entirely on a sustained-operation basis. The same purposes can be served by watching carefully the steam gage, or the speed indicator, but a back-pressure gage may give a more timely warning to the inexperienced engine driver. It cannot be, though, of such universal service as described in Mr. McBride's paper.

H. B. Oatley.[5] It is, of course, well-known that through the use of feedwater heaters, as well as exhaust-steam injectors, a portion of the exhaust steam is utilized for the feedwater heating. The effect in the locomotive cylinder, therefore, is that of a partial condensing operation and results in a very desirable decrease in the back pressure on the pistons through the entire range of operation.

In considering the reduction of back pressure, although it is not suggested in the paper, there is an opportunity for improvement in providing ample exhaust passages. This is a feature that is, of course, well known to the locomotive designers, and a great deal of progress has been made in recent years. In this same connection, the query has often arisen as to why steam-chest valves might not be made with double exhaust ports. There is much less difficulty in getting the steam into the cylinder than there is in getting it out, and it would seem that the double-ported exhaust valve should have advantages of moment as a means of reducing the back pressure.

The Author. Mr. Pearce, in his discussion, accepts the theoretical soundness of the use of back pressure to secure proper adjustment of the cut-off, but advocates a mechanical device to set the cut-off rather than dependence on the engineman and his attention to the back-pressure gage.

The paper was intended primarily to establish the principles involved and considered the back-pressure gage as a means through which these principles could be put into effect. Without doubt a mechanical device could and would adjust the cut-off more promptly and more accurately than could the engineman depending on the gage, but whether the mechanical device or the gage will be the better will doubtless develop with time.

The results obtained from the mechanical device as reported by Mr. Pearce in his discussion are certainly an endorsement of the general principle of the use of back pressure either to adjust

[5] Vice-President, in Charge of Engineering, The Superheater Co., New York, N. Y. Mem. A.S.M.E.

or to indicate the proper adjustment of the cut-off and its possibilities.

Mr. Symons, in his discussion, considers back pressure from the standpoint of the designer of the locomotive, a most important item mentioned in the first paragraph of the paper. Considered from this standpoint the back pressure should be as low generally as proper combustion of the fuel will permit; the back-pressure gage can be of little value, and Mr. Symons naturally concludes that there is no need for it. However, after the locomotive has been properly designed and turned over to the operator, the back pressure can then be used as a valuable assistance in operation. While, therefore, the importance of a low back pressure generally, as a matter of the design of locomotives is fully appreciated, the paper treats of an entirely different subject; that is, of the subsequent use of a specific back pressure in the operation of locomotives under certain operating conditions.

Mr. Oatley raises the question of the area of the exhaust ports, which is quite pertinent since any increase in area of exhaust ports would very probably lower the particular back pressure indicating maximum cylinder power, and also result in a slightly greater maximum cylinder power. However, the larger cylinder ports would not in any way interfere with the use of back pressure to indicate the proper adjustment of the cut-off for maximum cylinder power, but merely result in the use of a lower back pressure as the indication of that power.

Mr. Lipetz has submitted a very valuable contribution and does not agree with the author's conclusion. Unfortunately, however, he has used data from tests of a quite special locomotive, which tests were conducted only under conditions 1, 2, and 3 listed in the paper, whereas it is demonstrated in the paper that back pressure as an indication of proper adjustment of the cut-off can be of use only under condition 4; that is, where maximum cylinder power is desired. It is only natural, therefore, that Mr. Lipetz, because of the test data he has used, should not reach the same conclusion.

The quite special locomotive, the test figures of which were used by Mr. Lipetz, was designed for a special purpose which it has accomplished, but not for speeds high enough to develop the maximum power from its very large cylinders. Had this locomotive been designed for and tested with longer cut-off or higher speed or both and thus been representative of practically all other of our locomotives, then Fig. 3 submitted by Mr. Lipetz gives a good idea of what would happen. From the general trend of Fig. 3 it is evident that when extended to higher speed and longer cut-off, the top surface of the figure must flatten out at a level slightly under 4000 horsepower. Fig. 3 therefore demonstrates that slightly less than 4000 horsepower is the maximum power that can be obtained from these particular cylinders at any combination of cut-off and speed. Fig. 3 therefore confirms the author's Fig. 1 in its demonstration of the fact that the power that can be obtained from any particular cylinder, nozzle, and steam pressure is limited to a certain definite maximum. The back-pressure gage indicates when this maximum has been reached. When properly used the back-pressure gage prevents attempts to obtain more power than this maximum, i.e., the use of too long a cut-off with the consequent waste of steam and fuel, and also assures that this maximum will be obtained when desired because of its indication of the cut-off that should be used to obtain it.

The locomotive from which the test figures used by Mr. Lipetz were taken comes within the reservation made in the paper to the effect that "with the same back pressure more power is developed at higher speed and shorter cut-off," and in this differs from the locomotive the test data of which were used in plotting the author's Fig. 1. However, an investigation of the test data of the special locomotive indicates that "the maximum power for each speed is obtained at one and the same back pressure, and the usefulness of back pressure indication of proper cut-off to obtain maximum power is not lessened."

Fig. 1 of the author's paper was plotted from test data obtained from test of the Pennsylvania Railroad Mikado L1s. It is acknowledged that the L1s is not as modern a locomotive as the I1s but it is believed that the L1s well represents the majority of freight locomotives in this country and also all passenger locomotives as far as back pressure and cut-off adjustment for maximum cylinder power are concerned.

Present-day tendencies are leading more and more toward the more frequent requirement of maximum power from the locomotive. With the back-pressure gage or its equivalent and the consequent assurance that maximum cylinder power can be immediately and accurately obtained when required, locomotives will be loaded and speeded to a point where maximum cylinder power will be required of them even more frequently, and the need for the back-pressure gage or its equivalent will become more pronounced.

The author appreciates the valuable discussion which has been submitted and hopes that the paper, together with this discussion, will lead to a further study and a better understanding of the use that evidently can be made of back pressure to secure maximum cylinder power when desired, and that without waste, with a still greater increase in the efficiency of locomotives and their utilization.

# Heating and Ventilating of Passenger Cars

## The Need for Larger Steam-Heat Connections Between Cars in Long Trains; and a Description of the Automatically Controlled Vapor System of Car Heating

By EDWARD A. RUSSELL,[1] CHICAGO, ILL.

IN THE earlier years of passenger-car construction, little attention was given to car insulation or to the leakage of air through the crevices around windows and doors. These conditions permitted a natural ventilation by means of air currents which increased with train speed.

Today the improved steel-car construction (including effective insulation, elimination of crevices around doors and windows, and, in certain territories, the general use of double windows) has materially reduced the volume of air naturally changed even under high speed. These improvements in car construction, brought about in the interest of economy and comfort, make artificial ventilation necessary.

All exhaust ventilators now in use vary in capacity according to train speed. This variation is admittedly too great as between a car at high speeds and one standing still. It is also a fact that in passenger cars, even at reasonably high speeds, there will be "dead-air" spots, generally about midway between floor and deck, and at either side of the aisle, in an open-body car. The regulation of the exhaust capacity and the maintenance of a continuous and uniform change of air throughout the car, regardless of train speed or of wind direction and velocity, would result in increased comfort and economy.

The number of ventilators to be applied to a car should be determined by the capacity of the ventilator and the maximum number of occupants to be carried. The Master Car Builders' Association report and recommendations in 1908 showed that 1000 cu. ft. of fresh air should be supplied per hour for each passenger.

The present overheated and stuffy condition often present in cars standing at stations, can best be overcome by an arrangement whereby steam will be automatically shut off and a forced ventilation simultaneously begun whenever cars come to a stop. This could be further developed so that the amount of forced ventilation would be automatically controlled by train speed.

An efficient ventilation and heating system requires sufficient fresh air admitted by proper intakes, uniformly warmed by an easily regulated or automatically operated heating system, thoroughly circulated for the comfort of occupants, and exhausted by properly regulated mechanical means.

The heating of passenger cars has recently received special attention because of the difficulties that have been introduced by the advent of larger locomotives and the hauling of very long passenger trains. The increase of steam pressures necessary for car heating has rendered rubber hose unsatisfactory and uneconomical for steam connections between cars. Where rubber steam hose is used, a maximum of ten to twelve cars can be satisfactorily heated. In severe weather it is the practice on some roads to remove the steam hose, particularly on head-end cars, at the end of every trip and replace it with new hose, in order to avoid train delays due to burst steam hose.

A most timely editorial appeared in *Railway Age*, January 8, 1927, entitled "Car Heating Both Difficult and Expensive," in which it was stated that "tests have shown that a modern steel passenger car can be heated with about 2.85 pounds of steam per hour per degree difference in internal and external temperatures. This difference may reach 75 degrees or more, and in a 15-car train, therefore, 3200 pounds of steam per hour are required, or roughly eight per cent of the locomotive boiler capacity... A passenger car is essentially a room on wheels with a large proportion of window area, and exposed on all sides; and passes at high speeds through blizzards and sleet storms, and all kinds of inclement weather."

At the close of this editorial this very significant statement was made: "The flow of steam through two-inch pipe in train line is restricted in most cases, owing to the use of couplings between cars with only $1^3/_8$-inch openings."

In a later editorial (March 12, 1927), on "Heating Long Passenger Trains," it was stated that "with a maximum train-line pressure of 130 lb. at the reducing valve, it has been found impossible to heat the rear cars of a 15-car train to anywhere near 70 degrees. Under these conditions, it has been found necessary to have the initial train-line pressure materially higher to supply steam fast enough to be carried back to the rear car of such a train. The utilization of high steam-line pressures presents a number of difficult problems in design, maintenance, and operation that can only be solved by considerable study and experiment."

These two editorials indicate the problems that have to be met in car heating.

### Car-Heating Requirements

Essentially there are three requirements for ideal passenger car heating:

1 Sufficient volume and pressure of steam supply from locomotive for the adequate heating of every car in train;

2 Full-area steam passage through connections between cars, with minimum friction and freedom from leaks; and

3 Correct amount, distribution, and regulation of heating surface in each car to heat the car economically and satisfactorily under all conditions.

### Locomotive Equipment

For a number of years a 2-in. steam train line has been used under passenger cars, but the source of supply from the locomotive boiler is still restricted to a $1^1/_2$-in. outlet at the stop valve, with even smaller area for steam passage through the valve. This restriction necessarily retards the volume flow of steam to meet car-heating demands in severe weather, particularly on long trains. The use of a 2-in. stop valve, preferably of the angle type, constructed so that the valve seat lifts free from the path of the steam, will provide a greater amount of steam for car-heating purposes.

Essentially, then, this area should be maintained in reducing-valve connections in all steam-heat piping on the engine and in all steam-heat connections between engine and tender. Tests made by one of the large railroads, using a 2-in. stop valve and a 2-in. pipe to reducing valve, showed pressures at the reducing valve more than 10 per cent higher than those where a $1^1/_2$-in. stop valve and pipe were used with the same boiler pressure. It is important that the full area be obtained at the boiler outlet

[1] Engineer of Design, Vapor Car Heating Co.

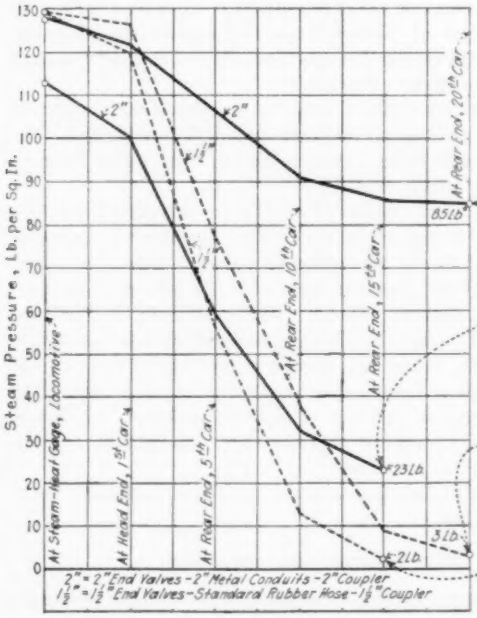
Contributed by the Railroad Division and presented at the Annual Meeting, New York, N. Y., Dec. 5 to 8, 1927, of The American Society of Mechanical Engineers.

TABLE 1 RUNNING TESTS

| Connections[1] between cars | Outside temperature, deg. fahr. | Average speed, m.p.h. | Pressure at steam-heat gage on loco. | Average car temperature, deg. fahr. | Average drop in pressure from head end of first car to rear of— 5th car | 10th car | 15th car | Average pressure at 15th car, lb. per sq. in. |
|---|---|---|---|---|---|---|---|---|
| WITH 15 STEEL COACHES | | | | | | | | |
| 2-in. metallic | −9 | 34 | 113 | 66 | 42 | 69.2 | 77.3 | 23.2 |
| $1^1/_2$-in. and hose | 10 | 36 | 129 | 67.5 | 63.4 | 106.8 | 116.8 | 2.6 |
| WITH 15 STEEL SLEEPING CARS | | | | | | | | |
| 2-in., metallic | 25 | 33 | 128 | 69.5 | 50.5 | 88.5 | 97.9 | 15.9 |
| $1^1/_2$-in. and hose | 13 | 39 | 147 | 59 | 69.2 | 114.5 | 125.8 | 0.0 |

50 per cent of ventilators open; from none to 50 per cent of intakes open, as required.

[1] 2-in. metallic: 2-in. end valves, 2-in. metallic conduits, and 2-in. steam couplers. $1^1/_2$-in. and hose: $1^1/_2$-in. end valves, $1^1/_2$-in. standard steam hose, and $1^1/_2$-in. couplers.




COMPARISON TABLE

| | Average outside temperature, deg. fahr. | Average pressure drop per car, lb. | Time to get steam to rear, minutes | Average car temperature, deg. fahr. | Average speed, miles per hr. | Number of deck sash open | Number of intakes open |
|---|---|---|---|---|---|---|---|
| Standing Test 20 Coaches 2" Vapor Conduits | 3 | $2\frac{1}{8}$ | $4\frac{2}{3}$ | 69 | — | — | — |
| Running Test 15 Coaches 2" Vapor Conduits | 9 | 6 | $5\frac{1}{4}$ | 67 | 33.6 | $\frac{1}{2}$ | $\frac{1}{2}$ |
| Standing Test 20 Coaches 1½" Rubber Hose | 23 | $6\frac{1}{4}$ | $29\frac{1}{2}$ | 70 | — | — | — |
| Running Test 15 Coaches 1½" Rubber Hose | 13 | $8\frac{1}{3}$ | $9\frac{1}{2}$ | 67.5 | 35.7 | $\frac{1}{2}$ | $\frac{1}{2}$ |

FIG. 1 VARIATION IN STEAM PRESSURES AT DIFFERENT PARTS OF A TWENTY-CAR TRAIN WITH 2-IN. AND $1^1/_2$-IN. CONNECTIONS

to the steam-heat line, and that the steam-heat piping on the locomotive be properly protected with covering.

Of more importance than is often recognized is the pressure-reducing valve used in the steam-heat line on locomotives. The length of train and varying outside temperatures determine the pressure and volume of steam required for car-heating purposes. Considering the maximum steam requirements for car heating—possibly eight per cent of the boiler capacity—it is important that the reducing valve should permit economy in steam consumption under other than the maximum requirements. The pressure-reducing valve, therefore, should be capable of adjustment to any desired pressure, and should maintain that pressure without fluctuation. A most important feature in the operation of locomotive pressure-reducing valves is the item of maintenance cost and the delay to the locomotive while making repairs; this has been successfully overcome by the adoption on many roads of a reducing valve so constructed that the cylinder walls and piston (the principal parts which wear or "wire-draw") may be quickly renewed without removing the valve from the pipe connections.

With present pressure requirements on steam-heat lines, rubber steam hose cannot be successfully used between the engine and tender and at the rear of the tender. Tests conducted in 1920 by the Montreal Air Brake Club showed a pressure loss between the reducing valve and the rear of tender of 13 per cent with standard $1^1/_2$-in. steam hose between engine and tender, and a pressure loss of 5 per cent with 2-in. metallic connections. Flexible metallic connections for this service should adapt themselves to any motion in service without restricting the steam areas.

With locomotives thus equipped, including all 2-in. piping and connections on tender, a higher pressure is available for car-heating purposes.

## CONNECTIONS BETWEEN CARS

The necessity for a full 2-in. steam passage through end valves, metallic conduits (used instead of rubber hose, which is not practical for high pressures), and couplers between cars has been proved by numerous tests.

As far back as 1922 it was demonstrated in actual service tests that when changing engines at terminals, steam would pass to the rear of a train equipped with 2-in. connections between cars in less than one-half the time required in a train equipped with $1^1/_2$-in. connections between cars.

Last winter, one railroad, in an effort to heat long trains of eighteen to twenty cars, removed the reducing valve from the locomotive and applied armored steam hose to all cars so that full boiler pressure would be available for car heating; but even with this arrangement the rear cars could not be heated in severe weather. Two-inch end valves and 2-in. metallic conduits were applied, leaving the $1^1/_2$-in. couplers which have only a $1^3/_8$-in. gasket opening. However, to heat the rear cars satisfactorily in extreme weather it was found necessary also to apply 2-in. couplers.

Another recent test indicated a pressure drop through the equivalent of five cars equipped with $1^1/_2$-in. end valves, rubber hose, and couplers which was 50 per cent greater than with the 2-in. connections between cars.

It has been found, where 2-in. metallic conduits are applied, that the saving in cost of steam-hose renewals over a period of two heating seasons in northern climate will more than cover the entire expense of the metallic conduits. Further maintenance economies will result from the use of metallic conduits constructed so that the gaskets and any other parts requiring renewal can be changed without special tools and without removing the conduits from cars; and by the use of gaskets with long life—made possible by arranging the conduit so there is no weight or strain on the gasket under any condition of service.

One railroad made a very exhaustive test last winter, with twenty cars standing in yards and with fifteen cars in train service, to compare the results obtained by using $1^1/_2$-in. connections (end valves, rubber hose, and couplers) and 2-in. metallic connections between cars. Fig. 1 and Table 1, compiled from this test, show conclusively the desirability of equipping locomotives and passenger cars with 2-in. steam-heat connections throughout.

A 2-in. end valve is necessary, particularly on long trains and end valves should have full-area unrestricted ports for

steam passage; should be easily and quickly operated against high pressures, and constructed to automatically hold the valve in open position to prevent train-line pressures closing the valve while in service.

Steam couplers should also be of 2-in. size and should be made with straight port through connected couplers. A positive locking arrangement (preferably with yielding tension to compensate for gasket wear) is necessary, and 2-in. couplers must interchange and lock with the present $1^1/_2$-in. couplers to permit their being operated with the present couplers during any period of transition to the 2-in. coupler as standard.

### Radiating Surface in Cars

Steam as a medium for heating passenger trains possesses many advantages over other methods, such as the hot-water circulating system or the electric heating system. In comparison with a hot-water system, the weight to be carried with a steam system is almost negligible; and steam has a decided advantage over hot-water in the matter of initial cost and maintenance expense. Another important feature in favor of the type of steam heating system generally used is that there is no danger from injury to employees or passengers in case of accidents which might break the heating pipes.

There is, of course, a special field for electric and hot-water heating systems. In strictly suburban service electrically operated cars are heated by electricity, although an electric heating system is more expensive to operate than a steam heating system. For main-line passenger cars, even where hauled by electric locomotives, the use of steam is far more economical, more flexible in regulation, and more desirable. It is the present practice on practically all railroads operating portions of their lines electrically, to equip electric locomotives (or a special heating tender between the electric locomotive and the first car of train) with a flash boiler of sufficient capacity to supply steam for car-heating purposes.

Of recent years hot-water circulating systems of car heating have been used only for auxiliary heating purposes on such cars as diners, business cars, and a few sleeping cars that are assigned to service where steam is not available at "lay-over" points and where the cars must be warmed for occupancy before the locomotive is attached. The development of self-propelled railway motor coaches on many railroads has increased the use of hot-water systems of heating.

The use of pressure steam-heating systems has been discontinued. They are neither safe in case of breakage of radiating pipes from any cause, nor economical in steam consumption. With pressure systems the cars in the head ends of trains were always overheated, and the traps were frequently frozen. While steam under pressure has a higher temperature, the difference is of no advantage in comparison to the objections and troubles arising from the use of pressure heating systems.

### Vapor System

The most universally used system of car heating today is the vapor system. The vapor system consists of a number of properly arranged heating coils inside a car. Live steam taken from the train pipe is admitted after the pressure has been reduced to atmospheric pressure by passing through a vapor regulator underneath the car. The heating pipes inside the car are divided into several independent coils or sections of radiating pipes, the number of coils and the amount of piping

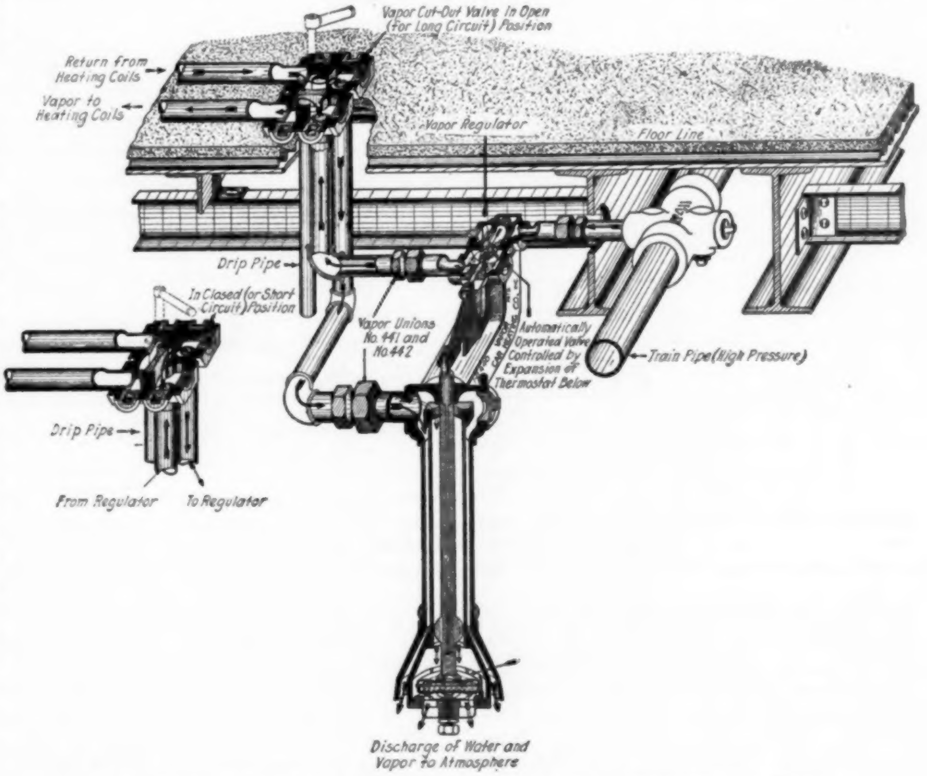



Fig. 2 Diagram of Control and Regulating Valve of Vapor Heating System

being determined by the interior arrangement of the car and its maximum heating requirements. Each coil or section of radiating pipes has a separate and independently operated cut-out valve by means of which, when the valve is open, steam at atmospheric pressure is diverted into its heating coil. The steam or condensate returns from the coil through the valve and back to the vapor regulator; or (if the valve is closed) the steam is bypassed from the valve directly to the vapor regulator, where the expansive diaphragm regulates the admission of steam from train line.

Variations in the temperature of the steam or hot condensate against the diaphragm in outlet of vapor regulator determine the amount of steam admitted from train line through the vapor regulator.

Fig. 2 illustrates the principle of the vapor-system operation. The "short-circuit" feature of the vapor cut-out valve keeps the extreme exposed outlet of the system warm at all times while steam is on the train line, regardless of whether any of the heating coils are using steam. This prevents freezing of the heating system.

With a vapor system, the heating pipes inside the car contain only steam at atmospheric pressure. The outlet of the system is always open to the atmosphere, so that pressure cannot build up in the heating pipes.

The temperature of steam at atmospheric pressure is 212 deg. fahr. at sea level and the heating pipes in all cars equipped with a vapor system are at the same temperature regardless of varying train-line pressures at the head end or rear of trains. The temperature of the steam or condensate at the outlet of a vapor system determines the amount of steam admitted through the inlet of the vapor regulator. A vapor system is thus economical in steam consumption, because only the steam actually required is taken from the steam train line.

In calculating the radiating surface required for a passenger car there are many conditions that must be considered, such as the kind of car, its construction, the tightness of windows and doors, the minimum outside temperatures encountered, and the maximum inside temperature required. There are definite heat losses to be figured. These vary somewhat, depending on methods followed in construction. Formulas for figuring conductivity of walls, floors, etc. of different materials and insulations, were given in a paper by K. F. Nystrom of the C.M. & St.P.Ry. presented at the February, 1924, meeting of the Canadian Railway Club. This paper also indicated the usual heat losses in steel passenger cars.

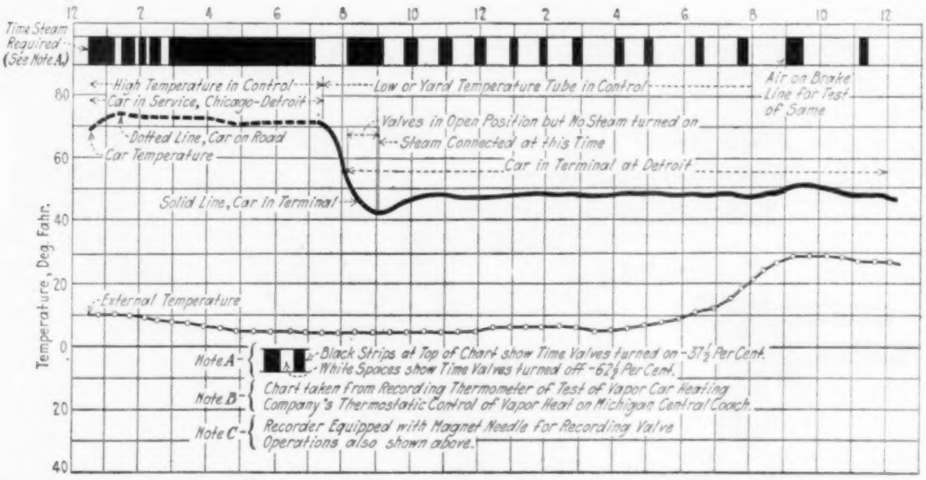



Fig. 3 Comparison From Tests of Steam Required in Service and at Terminal by Car Equipped With Double Automatic-Control Vapor System

(For car in service, valves are on 90 per cent of the time; for car idle, valves are on 23 per cent of the time.)

The total amount of radiating surface required in a steel passenger car is generally based on the ratio of one square foot of heating surface to thirteen cubic feet of space inside the car. This, of course, assumes that the car is properly insulated.

With the required heating surface arranged to permit the use of steam in the heating coils only as necessary to maintain proper car temperatures, correct temperature regulation is easily accomplished either through a manually or an automatically controlled vapor system. In the manually controlled vapor system the cut-out valves (see Fig. 2) for each heating coil are operated by hand.

In an automatically regulated vapor system the cut-out valves are operated electrically from the car lighting circuit, and are thermostatically controlled to admit steam into the heating coils as required to maintain predetermined car temperatures.

A heating system for passenger cars must be arranged to warm the car under all conditions of outside temperature, which, during a single trip on some roads often range from below zero to a point requiring no heat whatever. This necessitates extreme flexibility in methods of controlling inside car temperatures.

This is easily accomplished with the manually controlled vapor system, arranged (in the ordinary steel passenger car) with four separate and independently operated coils or units of radiation consisting of one three-pipe coil and one two-pipe coil on each side of the car. This arrangement permits the use of steam in 20, 30, 40, 50, 60, 70, 80, or 100 per cent of the maximum heating surface provided, and will satisfactorily heat a car under any outside temperature conditions.

The dependence upon the human element to turn steam on or off does not always meet the demand of the traveling public. Furthermore, cars lying over at terminals require heat to protect toilet water, etc. from freezing. The natural consequence is overheating of cars during the "lay-over" period. Improper manual regulation in service and overheating at terminals result in excessive steam consumption for car heating.

### Automatic Temperature Regulation

In the development of automatic temperature regulation for passenger-car heating the paramount consideration has been its resulting economy to the railroads. Normally a passenger car is in train service only one-third of the time. On some roads the average is more, and on some roads less. It is therefore important to avoid all unnecessary waste of steam by the usual overheating of cars lying over at terminals approximately two-thirds of the time.

There is no necessity for maintaining in cars in terminal yards the temperatures required in service. A 50-deg. car temperature in yards will prevent freezing of toilet water and permit cleaning and other work inside the car without discomfort. Such temperatures can be maintained at terminals by automatic temperature regulation.

To maintain by automatic means a temperature of 50 deg. in cars in terminals for two-thirds of the time, and, say, 70 deg. in service for one-third of the time, requires the use of two thermostats, each made to operate at the predetermined temperature, one for terminal control and one for service control.

The requirements of an automatically regulated vapor system are as follows:

It must retain the "short-circuit" principle of the manually operated vapor system in order to prevent freezing, etc.

It requires a double thermostat properly located in the car.

It must be designed to change automatically from the 50-deg. terminal-control thermostat to the 70-deg. service-control thermostat, or vice versa, without any manual attention. This is accomplished by the use of an air-operated contact switch, arranged so that the presence of air in the brake train line will put the 70-deg. or service thermostat in control of the heating system, while the absence of air in the brake line will put the 50-deg. or terminal thermostat in control.

It must be arranged so that the 70-deg. thermostat can be put in control manually when it is necessary to heat cars for occupancy and there is no air in the brake line, at the same time not affecting the automatic change from 70 to 50 deg., or vice versa, when air has again been connected to brake line.

It must have a valve mechanism which will not consume electric current constantly in either the open or closed position, and provision must be made for manual operation of the valves in case of failure of the car lighting current at any time.

The thermostats, magnetic valves, etc. must be protected

from damage by accidental excess voltage through wiring connections.

With the possible maximum use for car heating of 8 per cent of the total steam generated by the locomotive, it is very essential that every economy be made in heating passenger trains. An automatically regulated vapor system will maintain uniform temperatures in train service, increasing the comfort of traveling public, and will effect considerable economy in actual steam consumption. It will also eliminate unnecessary waste of steam in heating cars at terminals.

Fig. 3 shows the result of a 24-hr. test, both in service and at the terminal, of one car equipped with an automatically regulated vapor system. It will be noted that in service, with an average outside temperature of 6 deg., a uniform temperature was maintained in the car and steam was actually shut off automatically for 10 per cent of the time. In the terminal, steam was shut off 77 per cent of the time.

The saving in steam and coal consumed in heating passenger cars at terminals is further emphasized by a test made at a Chicago passenger yard of two 70-ft. steel passenger coaches, identical in construction and in the arrangement and amount of radiating surface, quoted below:

Both cars had arrived in the same train, and inside temperatures were the same at beginning of test.

Ventilators of both cars open; vestibule doors adjusted similarly; temperature readings taken, and all condensation measured at frequent and regular intervals.

Steam supplied both cars from same source, through a tee-connection.

| | Automatic-control car | Uncontrolled car |
|---|---|---|
| Outside temperature, 26 deg. fahr....... | .... | .... |
| Average inside temperature maintained during "lay-over," deg. fahr... | 53 | 83 |
| Percentage of time steam was used in radiating pipes.................... | 18 | 100 |
| Average condensation, lb. per hr....... | 33.35 | 124.76 |
| Average saving condensation, lb. per hr.. | 91.41 | |
| Or approximately.................... | 14 lb. coal per hour | |
| Total saving per car per year......... | 40,000 lb. (20 tons) coal | |

Also approximately 37,000 gal. of water.

(Above total saving based on the fact that passenger cars lie over at terminals or in yards practically two-thirds of the time, and allowing 188 days out of each year during which steam would be required in yards.)

Condensation from yard line drained before steam entered either car.

One car operated continuously under double automatic control vapor system, with the 50-deg. or "lay-over" thermostat in control.

Other car, similarly equipped, had the automatic control feature cut out, and was operating continuously with all valves in the "On" position or wide open, the usual way of heating "lay-over" cars.

In spite of numerous tests that have been made to determine the actual or average steam consumption required to heat passenger cars both in train service and at terminals, it may be said that no formula has been developed that will be accurate under all conditions.

Theoretically, approximately three pounds of steam per car-hour will be required for each degree of temperature difference to be maintained between outside and inside for an ordinary steel passenger car.

The diversity in types of car, their methods of construction and insulation, interior arrangements, number of exposed outlets of heating system, direction and velocity of wind, all affect the condensation of steam for car heating.

An important factor is the speed of train which automatically increases the amount of air exhausted through ventilators. As an indication of the relative increase in condensation with increased speed of train, note the following result of test made:

| Outside temperature, deg. fahr. | Pressure at steam-heat gage, lb. per sq. in. | Pressure at rear of 11th car: at 40 m.p.h., lb. | at 60 m.p.h., lb. |
|---|---|---|---|
| 27 | 110 | 40 | 30 |
| −8 | 110 | 30 | 15 |

The automatically regulated vapor system is also of considerable advantage in maintaining or periodically building up train-line pressures. During a test of a train (all cars equipped with automatically regulated vapor system) it was found that as the thermostats in cars automatically closed the admission valves and cut out steam from the heating coils inside the cars, train-line pressures increased. In one instance, presumably the result of thermostats in all cars shutting off steam about the same time, the pressure at the rear of the last car increased 25 pounds in ten minutes.

Proper insulation of all exposed piping and connections underneath the car will of course, aid the reduction of condensation in severe weather and at high speeds.

## Discussion

P. D. Mallay.[2] Last winter the writer made a rather extensive run on a train of test cars to determine the exact amount of steam which would be required to heat trains of varying length at different speeds under different weather conditions. One very noticeable fact was that for a train running under severe weather conditions at a speed of from 40 to 50 miles an hour, more than twice the available radiating capacity of the heating system was required to heat a car. It seemed that the following conditions might cause apparent loss of steam:

When the steam leaves the locomotive it passes through a reducing valve and then through the tender connection and in succession through the couplings between the cars. In most cars the opening in the coupling is 1 in. in size, the steam then expanding again into a 2-in. train line. It was observed that in passing over track pans the test steam flow in the test car dropped appreciably. After the pan was passed conditions reached nearly equilibrium, and the flow rose to normal. Those rides indicated that there were four important factors in the consumption of steam for heating purposes, as follows: (1) The major losses in throttling valves on the locomotive; (2) periodic throttling through the car couplings; (3) the production of eddy currents in joints of different types; and (4) losses due to radiation of the train line under the cars.

In trying to correct conditions it was found with some surprise that it was not economic to increase the thickness of the insulation on the lines to more than 1 in. The fact that the steam flow dropped considerably in passing over track pans led to the conclusion that one of the greatest factors of loss was condensation in the steam connections, and that naturally led to the assumption that they would have to be insulated. Can they be insulated? and if so, how? If the author's observations have been such as to lead him to conclusions different from those just recorded, his comments should add greatly to the value of the paper.

H. B. Oatley.[3] The Long Island Railroad has been using superheated steam for train heating for a number of years, and has reported some very satisfactory results both as to the saving in fuel on the locomotive and in the more constant heating of the cars. It is reported that the railroads in the Northwest, particularly those roads operating with the extremely long transcontinental trains containing as many as 15 or 18 cars, operating

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[3] Vice-President in Charge of Engineering, Superheater Co., New York, N. Y. Mem. A.S.M.E.

as they do through the extreme low temperatures of the winter, down to 30 and 40 deg. below zero fahrenheit, have been considering its use. It is believed that they can heat the entire train by using superheated steam on the train line and avoid the necessity of using individual car-heating equipment in the last four or five cars of the train.

In that connection the question has come up of whether or not the rubber hose connections between cars would stand the higher temperatures of superheated steam. Some of the roads are using metallic connections, but the Long Island apparently is using the rubber hose. It is difficult to figure a thermal gain by using superheated steam—heating is simply a question of transferring heat units—but the argument in its favor is that steam can be forced back further in the train because condensation does not take place as quickly as with saturated steam, and therefore a given size of heating line ought to carry the heat further.

H. W. Fitch.[4] Information from Mr. Russell on the extent to which superheated steam has been used for car-heating should prove valuable.

G. M. Eaton.[5] Quite often a question arises as to the quantity of energy required to heat a train of cars with steam generated electrically, and the following may be interesting. A good many years ago when the Pennsylvania was considering electrification from Manhattan Transfer to New York, a test was run on an electric train-heating boiler installed on an electric locomotive. Operating on the West Jersey & Sea Shore in zero weather with a full-capacity train, as the writer recollects it, the records showed that the boiler required about the same energy to heat the entire train that the locomotive required for hauling the train.

[4] Mechanical Inspector, New York, New Haven & Hartford R.R. Co., New Haven, Conn. Jun. A.S.M.E.

[5] Engineer, Molybdenum Corp., Pittsburgh, Pa. Mem. A.S.M.E.

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# The Motor Truck and L.C.L. Freight

BY F. J. SCARR,[1] NEW YORK, N. Y.

*The railroads are economically best suited for the wholesale movement of freight. The controlling factor in their operation is terminal capacity, and terminal costs and delays are the chief obstacles to their greater participation in the short-haul movement of less-than-carload traffic.*

*Under the present methods and conditions, the highway operator can move most less-than-carload freight for considerable distances cheaper than the railways. He will continue to maintain an economic advantage for the shorter terminal hauls, but a new instrument of freight transportation, the unit freight container, will permit the profitable rail handling of much of the traffic now trucked greater distances. This will necessarily result in the restoration of this traffic to the railways.*

*The container will use both the highway vehicle and the railroad in the portions of the total movement for which they are best fitted. The rail cost of less than one cent per ton-mile—or about one-seventh of the cost of movement by motor truck—will apply to the road-haul portion, and the terminal cost will be decreased because of the elimination of at least four man-handlings of the freight. The most important collateral benefits are:*

1. *Faster handling of freight from shipper to consignee*
2. *Relief of terminal congestion*
3. *Elimination of theft and damage claims*
4. *Reduction in packing and carting costs*
5. *Reduction in rolling stock devoted to L.C.L. service.*

TRANSPORTATION has advanced in economy and efficiency in proportion to the intelligent application of human ingenuity and capital investment. True advancement, however, is not in the development of any single phase to usurp in whole or in part the function to which any other phase is particularly adapted and better fitted to perform. A proper scheme of transportation demands that each means be employed in the task for which it is best suited.

President L. F. Loree of the Delaware & Hudson Company, in his address before the Holland Society last year, discussed the advancement of transportation in a unique manner. He measured such advancement by the increased productivity of the individual as outlined in the following quotation, which—with Mr. Loree's permission—has been briefed:

> The first transportation undertaken by man was a personal effort in which he packed his own burdens.....Under this method there may be transported daily 65 pounds 15 miles for each porter, or allowing 312 days for a year's work, 152 ton-miles.
>
> With the domestication of wild beasts, pack trains were organized....A horse of average force working for eight or ten hours per day might transport on his back 200 pounds at a rate of 25 miles per day over average level country. For a year of 312 days his performance would be 780 ton-miles.
>
> In the early eighteenth century.....highways were built with careful attention to grades and their surfaces properly metaled. Many cartage companies were organized and an allowance of one ton of goods for one horse was very general. With this power, 20 miles a day were covered, or for a year of 312 days, 6240 ton-miles....
>
> There were on the payrolls of the railroads of the United States at the end of 1925, 1,753,208 employees. Making a rather arbitrary division of these employees between freight and passenger service.... indicates that there were approximately 1,415,000 employees engaged in freight service. In the year 1925 the railroads transported 452,827,593,844 net tons one mile. Comparing the extremes only, we have 152 ton-miles per year as the paying load-carrying capacity of the porter. The railroads in 1925 transported 320,019 (paying load) per individual freight employee. That is, the productivity of the individual due to the achievements of management, as reflected in the concerted movement and in the ordered discipline; the use of capital reflected in the plant, the provision of power, and the multitudinous inventions and adaptations of machinery and tools; and his own intelligent industry, has been multiplied 2105 times.

For the purposes of this discussion, the productivity of the individual has been calculated when using the motor truck, the latest development of land transportation. These results, together with those previously discussed, have been listed in Table 1 for convenient comparison. This is offered not as conclusive as to accurate detail, but as indicative of general relations.

TABLE 1 PRODUCTIVE ABILITY OF THE INDIVIDUAL

| Means of transportation | Revenue freight per man per day | Miles transported | Ton-miles per year per man | Cost per ton-mile |
|---|---|---|---|---|
| Porter | 65 lb. | 15 | 152 | $10.250 |
| Pack horse (6) | 1200 lb. | 25 | 4,680 | 0.933 |
| Horse and cart | 1 ton | 20 | 6,240 | 0.380 |
| 2-horse dray | 2 tons | 20 | 12,480 | 0.240 |
| 5-ton truck | 5 tons | 100 | 156,000 | 0.065 |
| American railroads[1] | 3.06 tons | 309 | 295,000 | 0.009 |

[1] 1925 actual performance; other figures are potential.

While it is recognized that the figures in Table 1 are not accurately comparable, there are certain general and interesting conclusions apparent which are adequately supported and justified.

It is interesting to note the distinct periods into which this table divides transportation development. These periods are clearly marked in the two columns captioned "Ton-miles per year" and "Cost per ton-mile."

In the first period neither capital nor human ingenuity have been applied to an appreciable extent, with a minimum of individual ability and maximum cost as the result.

The second period finds the application of capital in the form of muscular power and the application of human ingenuity only to the extent of animal domestication. The result, however, is to increase individual productivity thirtyfold and reduce the cost by ninety per cent.

The third period is that of additional capital use and the first application of mechanical invention in the cart and dray. The result is again to increase productivity and reduce cost.

The final period seems to be the acme of development, as Mr. Loree points out in the last sentence quoted from his address. Herein the supreme application of human ingenuity, in the development of mechanical power as well as greatly advanced auxiliary means, is made possible by the unstinted and intelligent application of capital in the form of railways and motor vehicles. This has resulted in increased individual productivity and reduced costs to a seemingly extreme degree.

It seems that the final period has been reached. Advance from the present state will be the result, principally, of refinements of established principles and practices.

The general direction of such refinements is clearly indicated by the fundamental relations of our various means of transportation. Table 1 establishes in a general way the relative merits of the various forms of land transportation.

The railroad is supreme in its "mass transportation" ability. Economic law dictates its utilization to the greatest possible extent for the movement of that class of freight for which its equipment and facilities have been designed—in general, the movement of large volume for long distance.

[1] Scarr Transportation Service, Consulting Engineers. Assoc-Mem. A.S.M.E.

Contributed by the Railroad Division and presented at the Annual Meeting, New York, December 5 to 8, 1927, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

The porter is supreme in his individual-package movement or retail transportation ability. His capacity, short radius of action, and high cost confine his field to the narrowest of limits.

Each means of transportation bears a definite relation to the others and to the general scheme in proportion to the traffic which its relative but varying limitations particularly fit it to handle.

### The Railroad and the Motor Truck

As this discussion is primarily one of the motor truck and a portion of the railroad scheme, it is necessary to examine the general relation of these two means more specifically. Therefore the data in Table 1 have been extended into further arbitrary divisions, as shown in Table 2.

TABLE 2 PRODUCTIVE ABILITY OF THE INDIVIDUAL

| Part | Means of transportation | Tons of revenue freight per man per day | Miles hauled | Ton-miles per man per year (312 days) | Cost per ton-mile |
|---|---|---|---|---|---|
| I | American railroads (All freight) | 3.06 | 309 | 295,000 | $0.009 |
| | American railroads (C.L. freight) | 3.43 | 309 | 330,700 | 0.008 |
| II | American railroads (L.C.L. freight) | 0.85 | 309 (?) | 82,900 | 0.032 |
| | 5-ton truck[1] | 5.00 | 100 | 156,000 | 0.065 |
| III | 5-ton truck (80 per cent load) | 8.00 | 33 | 82,400 | 0.090 |
| | 5-ton truck (40 per cent load) | 5.00 | 33 | 57,500 | 0.215 |
| | American railroads (L.C.L. freight) | ... | 33 | .... | 0.160 |
| IV | 5-ton truck (80 per cent load) | 16.00 | 10 | 55,900 | 0.115 |
| | 5-ton truck (40 per cent load) | 10.00 | 10 | 31,200 | 0.250 |
| | American railroads (L.C.L. freight) | ... | 10 | .... | 0.490 |

[1] Potential figures.

### Railroad to Handle Much of L.C.L. Traffic

Less-than-carload traffic constitutes approximately 4 per cent of the total railroad freight business and requires nearly 20 per cent of the rolling equipment for transportation. Table 2 (Parts 1 and 2) indicates that the handling of L.C.L. freight costs four times that of carload freight. This is due, primarily, to high (L.C.L.) terminal costs and low average tonnage per employee.

The potential performance of the motor truck exceeds the individual productivity of the L.C.L. freight employee. The greater cost per ton-mile, however, presents the complete usurpation of this business by the motor truck, and indicates that for much of this class of freight the railroad must remain supreme.

High railroad terminal costs, due principally to the high platform-handling expense, cause a material change in this relation for the shorter distances.

### Railroad Terminal Costs Favor Motor Truck for Short Distances

At 33 miles, the economic point below which the average railroad cost of handling L.C.L. traffic exceeds the revenue, the relation of the railroad and the motor truck is such as to favor the latter under good motor-trucking conditions and the former for average conditions.

At this distance, on the basis of cost alone, the railroad is superior to the 40-per-cent-load-factor motor truck,[2] while the 80-per-cent-load-factor vehicle[2] is capable of serving at less cost than the railroad and will also reduce the time element to the minimum.

It is assumed that ten miles is the outside radius of the daily ability of the horse-drawn vehicle. This distance is well within the reach of the motor truck, which vehicle seems destined to play a middle role between the horse-drawn vehicle on the individual or retail side and the railroad on the mass or wholesale side. Dependable statistics indicated that, of the large and ever-increasing amount of traffic being handled over the highways, nearly 50 per cent is moved less than ten miles. At this distance, as indicated in Part IV of Table 2, the motor truck is eminently supreme, both in cost and expedition of movement.

[2] These percentage load factors are approximations of the average attainments of organized motor transport for "one-way" and "two-way" loads.

### Present Conditions at Variance With Economic Law

While economic law is certain to prevail, it is not as prompt of action as it is correct of judgment. Human effort to influence the functioning of this law is slow of adjustment to meet new developments. The cost of operation, while indicating the economic relation, is not a correct measure of the conditions which influence the flow of today's freight traffic. The cost to the shipper, involving arbitrarily fixed rates, and to a material extent the expedition of completing the through movement from door to door, are the chief factors affecting a choice of mode. These factors, considered in their true light, together with other related factors, present a vastly different picture of the present relation of rail and highway transportation.

### Shippers Interested in Complete Movement

No transportation is of value except as a part of the completed movement from point of origin to point of destination. That the shipper is also interested in the element of in-transit time is evidenced by changed business conditions and demands. The through movement and minimum costs, however, remain the shipper's prime interest.

In the movement of L.C.L. freight traffic the railroad performs, in general, but one portion of the completed movement. Some form of highway transportation accomplishes the collection and distribution. This condition is also true of a considerable portion of carload merchandise traffic.

The shipper is also burdened with the necessity of crating merchandise. That this item is of greater expense and weight when railroad movement is contemplated than when only highway transportation is involved, is well known.

### Through Movement

The through movement from origin to destination involves, generally, three and four elements of expense when moved respectively by highway alone or by highway and rail. These factors are: Crating, Carting, Freight on Net, and Freight on Tare. These factors in combination determine the true relation of rail and highway transportation as dictated by today's conditions. Properly evaluating these elements of the completed movement indicates that the motor vehicle can successfully (and actual operations demonstrate) compete with the railroad handling of L.C.L. traffic for considerably greater distances than the accurate measure of economic law seems to dictate.

Today's conditions are not in accord with economic law. In spite of the human tendency to resist any change in the established order, the shortcomings of the present system will be overcome and the advantages offered by new measures will be pursued.

The motor vehicle is burdened with little terminal expense. The railroad, particularly in L.C.L. traffic, is tremendously taxed by high terminal costs—made up largely of handling expense. These characteristics are clearly demonstrated in the flat motor-vehicle and abruptly ascending L.C.L. cost curves for the shorter distances.

1 High railroad-terminal L.C.L. expense must be reduced
2 High motor-vehicle line-haul expense must be avoided.

### Coordination of Effort

These principal expense factors of the two modes of transportation under consideration can be bettered materially by mutually coordinated effort. In the matter of terminal expense the motor vehicle is reasonably free, that item being largely absorbed by the merchant, while the railroad pays from $0.16 per net ton-mile (at 33 miles) to infinity, depending inversely upon the distance. In line-haul expense the motor vehicle is penalized a fairly constant sum of $0.065 per net ton-mile, while the railroad does not exceed $0.032.

Two conclusions result directly from the foregoing discussion:

1 To permit the utilization of railway transportation in the line haul and highway transportation in the terminal movement to the greatest possible extent demands that some efficient, economical, and rapid means of transfer from one medium to another be devised and placed in service.

2 To permit the application of a plan of mutual coordination between rail and highway transportation requires that present rate structures be revised to be as fully as possible in accord with the relative cost of operation of each mode.

### The Unit Container

Accepting these seemingly academic but exceedingly real and practical conclusions as correct, the manner of making them effective is immediately of interest. The refinements that are necessary in advancing from our present state are simple and of proved practicability. The unit-container method of handling L.C.L. traffic will go far in the accomplishment of the above purposes.

It is not proposed to discuss here the advantages or probable method of applying the unit container to our transportation requirements. For an able discussion of this new and important phase of transportation, reference is made to a recent paper entitled, "The General Theory of Container Use," prepared by Bernard Allen, one of the author's consulting-engineering associates. Mr. Allen has also taken up the subject in a recent issue of the *Railway Age*. Here is a railroad man of many years' experience with the Canadian National Railways looking forward to the general and widespread acceptance of this specialized method of handling L.C.L. freight traffic. The unit container is not new, nor is its application to a coordinated plan of rail and highway transportation new. Such plans have been advocated and to some extent successfully utilized for a great many years; the first patents being granted on such devices in England in 1845.

The conditions, however, which make its general and widespread use certain within the near future are of reasonably recent development. The motor vehicle, with its flexibility, has not only made container interchange possible and from an economic standpoint desirable, but has brought on a demand for the type of service that its adoption will augment. The high cost of platform labor has forced the adoption of all possible labor-saving devices to keep the costs within the regulated revenue.

New business demands for lower inventories and more frequent shipment of smaller quantities with consequent shortened warehouse clearings have created conditions particularly appropriate to usher in this new development.

As other special classes of traffic have been served by special equipment and facilities, so L.C.L. traffic—the most expensive division of the railroad business—will gradually be accorded the same treatment, with correspondingly favorable results in increased efficiency and economy. The present stage of transportation development will by this means have advanced through additional refinement, with advantage to individual productivity, cost, and the shipping public.

## Discussion

K. J. Ammerman.[3] The setting up of the motor truck as a competitor of the railroads has been the result of a number of factors the importance of which has kept pace with the increase in population and the ever-increasing congestion in and around the large cities.

Years back, when this congestion was not as marked as it now is, the railroads were able to carry from place to place in a reasonable length of time the commodities and types of freight which have to a certain extent been lost to them. Perishable farm products and rush freight in small lots which have to be carried a relatively short distance, say, 75 to 100 miles, are referred to particularly in this connection. With the increase in traffic of all kinds the congestion in railroad terminals has become so great that the length of time required to move freight from the outskirts of the city into the freight terminal represents about two-thirds of the total time required to haul the commodity from its source to the terminal. Under such conditions it was found that a motor truck could carry such freight in one-half the time required by the railroad.

To increase the size of terminals so that the congestion would be comparable with that which existed years ago would be too costly. It seems to the writer that a further recognition of the motor truck as an ally rather than as an enemy of the railroad would achieve the desired result of returning a large percentage of the lost freight, by reducing the shipping time through the establishment of freight terminals on the edge of the congested area and delivering freight direct to the consignee from that point. By so doing, the time from consignor to consignee would be cut to a point no overland trucking company could approach.

The comparison of truck speed and railroad speed is all in favor of the railroad until the congested area is reached. From that point to the consignee the time would be the same either by a local truck or overland truck, less the time of transferring the freight from railroad to truck.

The margin of time in favor of the railroad on the major portion of the haul would more than cover the transfer time. This margin of speed, however, is rapidly being reduced through the very noticeable tendency toward heavy trucks capable of speeds formerly thought possible only in light trucks.

The above-mentioned method would not militate against the trucking interests, as local trucking would be more profitable than the overland haul, provided the railroads and trucking interests cooperated in adjusting rates to their mutual satisfaction and still did not increase the rate to the shipper.

W. C. Sanders.[4] The paper is very interesting, especially that part which deals with the cost of L.C.L. freight by steam road and by motor truck. The limiting factors of each are very clearly brought out.

The motor truck undoubtedly has a definite place in the transportation system of the country as an adjunct or supplement to the steam roads, holding a position similar to the bus, and it affects steam passenger service.

The writer believes that L.C.L. freight containers with night pick-up service, using either gas-electric or oil-electric motive power, will greatly reduce the cost of L.C.L. short-haul freight.

The advantages of the container-car system are as follows:

1 It will furnish a means of expediting delivery of less-than-carload lots of commodities by eliminating the time and expense of rehandling, checking, and trucking.

2 The immediate unloading and loading of containers promptly

[3] American Car and Foundry Motors Co., New York, N. Y.

[4] General Manager Railway Division, Timken Roller Bearing Co., Canton, Ohio. Mem. A.S.M.E.

releases rolling stock, clearing the yards of cars and reducing congestion.

3 It will tend to keep the car moving at all times, making possible double the mileage now made by an ordinary piece of rolling stock in L.C.L. freight service.

4 It will allow a considerable reduction in terminal costs.

W. E. Symons.[5] With respect to the use of the motor truck and bus and their relation to the railway industry, there are a number of points of interest, some of which are somewhat clouded by a rather unfair view of the situation. To illustrate conditions, let us paint a picture of a typical American city and its surrounding territory, with railways radiating in all directions. Imagine an industry out in one direction making container boxes, let us say, which are required by another industry off in another direction. Assume these towns to be 15 miles from the city. The usual method of procedure is to order from the manufacturer of the container a carload lot either by telephone, telegraph, or letter. This is then transmitted to the railway operating office; it goes to the trainmaster, then to the yardmaster. A box car is selected for the shipment; it is taken over and delivered to another railway; then it is hauled out to where it is to be used, and finally loaded. It may be the shipment goes out on this line. Two, three, or even seven days may pass before those containers are delivered.

With the use of the motor truck the order is simply telephoned to the container manufacturer. A truck is backed up to the factory and in two or three hours the order is carried across to the buyer and the shipment awaiting the containers is on its way inside of 24 hours.

If a manufactured article is of a character requiring extra-heavy packing or casing for foreign shipment or for great distances, and lighter for local deliveries, in truck shipment the character of the container is much simpler, and its cost, which is always passed on to the consumer, is much reduced. Sometimes it is possible to dispense with it entirely. The railways have been somewhat backward in urging the use of trucks for this work, and in cooperating with the companies that provide trucks.

Another interesting and important feature is the passenger business. About a year ago a member of the passenger department of a certain railway at a meeting solicited the aid of the other passenger representatives in securing some protection against the inroads of the motor bus. He cited the fact that his company had lost a million dollars in passenger business the year before. He was very much disturbed about it. However, he failed to note an increase of freight earnings of about $40,000,000, a great deal of which was due to the fact that salesmen, using automobiles or motor buses, had driven through the country instead of relying upon local passenger trains of uncertain schedule. They were then able to visit six, eight, and sometimes ten towns per day, and consequently increased the freight shipments over that road several carloads. Such records when properly analyzed not only speak well for the use of the motor truck, automobile, and motor bus, but show that they are a help to the railways rather than a detriment.

There is one other feature, however, on which the railways have a just complaint, it seems to the writer. It is this: Taxes of the railways have crept up from about $100,000,000 to $400,000,000 per year. A great deal of this money has been used in building highways on which competitors of railroads may haul freight and passengers; in other words, the railways have been forced to aid in building a superstructure on which their competitors may do business. That is not fair, and there should be some readjustment to relieve the situation.

[5] Associate Editor, Engineering Publications, Angus Sinclair Publishing Co., New York, N. Y. Mem. A.S.M.E.

One more feature: Every one who has to do with shipping knows that there is a great deal of trouble in getting claims for damages or loss adjusted. It is not that the railways want to be unfair, but because the evidence or facts are frequently difficult to obtain, and sometimes it is very confusing because the articles pass through so many hands. But in the case of an immediate delivery by motor truck, the man who receives the articles and makes the deliveries is usually authorized to give a slip for damage or for loss of an article, and therefore the adjustment can be made immediately and be made accurately and satisfactorily to both parties concerned. There is an excellent field to be developed in this direction.

N. D. Ballantine.[6] The writer can certainly concur in the idea that there is a real field for motor vehicles in coordination with railway service in this country. It may be of interest to know that in six years, from 1920 to 1926, there has been a decrease of more than 25 per cent in less-than-carload traffic carried by class 1 railroads. Now that is not a measure of actual loss to the railroads because they actually had about 50 per cent more cars of less-than-carload freight. That works out in this way: If a given amount of merchandise is moving between two points, the railroad has to provide a certain number of L.C.L. or "way-freight" cars as we term them. Let us assume that it has to run one car which is capable of handling practically ten tons of merchandise, but an independent trucking concern hauls five tons of it. The railroad's cost of service in moving the ten tons is so small over the cost of handling five tons that it is rather difficult to determine what it amounts to, because the terminal charge is already practically taken care of in both cases. Hence there is a loss of revenue from 5 tons and no appreciable reduction in expense.

From this it is evident that the 25 per cent reduction in less-than-carload freight revenue referred to above does not in any wise measure the actual loss to the carriers. The same principle applies with respect to a lot of their passenger traffic.

The use of the container involves a more difficult problem and it is analogous to that of the mariner; it is not the "average depth" he wants to know—if he hits the high spot he is out of business. It is specific problems that have to be analyzed in the case of a container. If one uses a flat car, for example, he has this problem: About 60 per cent of all the carload traffic is east- or north-bound, and about 40 per cent moves in the other directions. The percentage in loaded box cars, which carry the L.C.L. freight, is probably greater than that, although the exact figures are not at hand, and probably are not available. There is a predominant and excessive west-bound movement of empty box cars throughout the entire United States. The protection of merchandise in a west-bound car that otherwise would move empty is not such a serious problem if it is put in one or two cars.

Let us assume that empty box cars are moving into a grain territory and that a shipper has merchandise to move from a jobbing point to the grain territory. Suppose ten tons are loaded into one car and that there is an empty car to move to the same point. It is better to use two cars and put five tons in each car, distributing one here and one there, and thus save time by relieving the crew of handling five tons. In other words, a certain amount of intermediate train expense is eliminated.

The tonnage per car for a carrier of less-than-carload freight is not an indication in any way of the efficiency with which the cars are utilized, because oftentimes a reduction in the number of tons per car on west-bound merchandise box-car loading is a very much more efficient procedure than the other method.

[6] Consulting Engineer, New York City, N. Y.

# High Steam Pressure and Condensing Exhaust for Locomotives

## A Discussion of Present Progress—Cycle Efficiencies—Auxiliary Requirements—Machine Efficiencies—Transmission Efficiencies—Thermal Efficiencies—Value of Locomotives—Possible Turbine Arrangements

By JAMES M. TAGGART,[1] NEW YORK, N. Y.

INCREASING steam pressures for power production always has for its primary objective an economy increase. For different Industries the economic return will be the result of different factors. Thus with industries requiring high-pressure steam for their processes an advance in generating pressure often will provide for power generation above the process pressures. In this case a decrease in first cost due to the smaller boiler plant required normally will be joined to a large reduced fuel or power cost to increase the economy. In central power-station practice the only increase in economy to be expected at present is a decrease in fuel charged per unit produced. Normally this saving must be balanced against an increased fixed charge to ascertain the resulting economy. There is also present in the case of central stations and most industrial plants the question of special design that may, if not successful, increase the maintenance costs.

For railroads higher steam pressures promise an increase in capacity as well as a decrease in fuel requirements. As will be pointed out later, the increase in power capacity will be approximately in a direct ratio with the increase in thermal economy. Since fuel cost is only about 25 to 35 per cent of the cost of locomotive operation, it follows that the capacity increase to be anticipated is three to four times as important.

With railroads also numerous like units are normally built at the same time. Accordingly, the uncertainties and high cost of special design can be largely avoided by preliminary trial tests.

It is thus evident that investigations to determine the optimum pressure of steam generation for central stations or other industries do not apply in considering steam-driven locomotives.

### Present Progress

In Europe where fuel conservation is relatively more important than in the United States, two designs of super-pressure locomotives have been built. One of these, namely, the Schmidt-Henschel locomotive, has in addition to the super-pressure section a lower pressure of steam generation. The drive for this locomotive approximates the standard. The other super-pressure locomotive, namely, the one built by the Swiss Locomotive Works, generates all the steam at 850 lb. per sq. in. and uses a high-speed, triple-expansion engine with a gear transmission for driving. These super-pressure locomotives are non-condensing. Condensing effect has, however, been applied to several types of turbine-driven locomotives that have been tried out in Europe. The trials have shown an improved thermal economy. In addition to the super-pressure locomotives and the condensing locomotives a number of locomotives in Germany have been equipped with the uniflow type of cylinder.

### Limits

Apparently these different developments have to some extent a common bearing. Thus, condensing effect with its promise of a cleaner feedwater is especially important with super steam-pressure generation, while any form of drive that will more economically utilize steam expansion has an enhanced valuation when the range of pressure is increased.

With this in view the estimates and computations in this paper are based on equipment including condensing effect and consideration of both turbines and uniflow-cylinder drives. In order to confine the treatment within reasonable limits, general arrangements and types of designs have been taken as a basis for the theoretical treatment. These are listed below and are more fully described in the September and October, 1927, issues of the *Railway Mechanical Engineer*. In no case is there an extension of effects beyond a possible economical practice.

Boilers—water-tube, preferably non-water-line, constant-temperature type

Economizers and superheaters—to form a part of the boilers

Furnaces equipped for pulverized- or liquid-fuel burning

Air preheaters

Forced- and induced-draft fans

Auxiliaries—motor driven in most cases

Feedwater heating

Condenser—probably of the air-evaporative-cooled type

Main drive arrangement—either

1. Turbine with gear transmission
2. Turbo-generator-motor drive
3. Engine, uniflow, multiple expansion direct
4. High-pressure engine direct and low-pressure turbo-generator motor.

For arrangements Nos. 3 and 4, see Figs. 19, 20, and 21.

### Assumptions

Calculations involving steam at the higher pressures are subject as yet to some uncertainty. It is a field where the authorities and most of the tests made vary. The variance is, however, not enough materially to affect the results. For this paper the enlarged steam tables of Prof. H. L. Callendar have been used.

Assumptions of conditions of operation are limited by numerous factors. Thus in the equipment listed the boiler is mentioned as one of constant temperature. With the non-water-line boiler the control would be adjusted to produce the desired temperature, and with a reliable control a higher temperature could be carried than where dependence was placed on calculated heat transmissions. Thus in the latter case greater leeway would need to be allowed for unusual fire conditions. A figure of 700 deg. fahr. has been taken as a conservative initial steam temperature now in use. With this temperature as a normal maximum and with good design all parts can be made up from standard materials. It seems probable that in the near future 800 deg. fahr. may be safely used with special high-temperature steels. Accordingly values have been given also in most cases for 800 deg. initial temperature.

Volume requirements and atmospheric temperatures limit the economical vacuum. An absolute pressure of 2 lb. has been assumed for the condenser pressure. This assumption is

[1] Consulting Engineer, New York, N. Y. Assoc-Mem. A.S.M.E.

Presented at a meeting of the Metropolitan Section of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, November 15, 1927.

based on an estimate of performance at 70 deg. fahr. atmospheric temperature. A further cooling effect of the liquid down to 100 deg. fahr. is assumed in determining efficiencies. Thus 100 deg. fahr. is considered as the temperature of the boiler-feed pump suction, whether taken partly from the condenser or all from the supply tank into which the condensate is discharged. In practice the vacuum would vary with the load as well as with the air temperature and flow.

The size of the locomotive power plant as well as the space requirements limit the economic value of complicating the equipment to reduce fuel consumption. Some arrangement of feedwater heating is apparently necessary for good results at high pressures. The type and design of the drive and heaters provided would determine largely the number in series that could be advantageously used. The best location of the heater or heaters relative to their operating pressures also depends to some extent on the form of drive. Normally two heaters, of the closed type, in series have been assumed. With the heater efficiencies probably attainable, a third effect would hardly seem justified. A better heater efficiency such as is obtainable with open heaters or special conditions might change this conclusion. Curves of cyclic efficiency (Fig. 5) are also given for a single closed-heater and a double open-heater cycle. These are for comparison only. All thermal efficiencies unless otherwise noted are based on the use of two closed heaters in series. These heaters are assumed as draining and venting into the steam space of the heater of next lower pressure, and into the condenser from the lowest-pressure heater.

Values are given for one 100-deg. fahr. reheat effect in addition to the regenerative effects. It is probable that usually the installation of reheat equipment will not be economical. Arrangement No. 4 appears, however, to be a possible exception. Furthermore it seems possible that in the near future a mercury-vapor reheater may be developed that may change the situation.

## Cycles

Referring to combinations of steam flow as cycles is convenient and in accordance with recent practice, though it is extending the meaning of the word "cycle." Thus bleeding a prime mover at different pressures to successively raise the temperature of feedwater comprises in fact a number of separate cycles, and in the author's experience was formerly called "series heating." It is here for convenience referred to, as suggested in the paper of Messrs. Hershfeld and Ellenwood published in the 1923 Transactions of the A.S.M.E., as the "regenerative cycle," and is indicated below and on the figures as the S-cycle for brevity. Where reheat is added the cycle is referred to as the SR-cycle. Figs. 5 and 6 show straight Rankine-cycle efficiencies for comparison. They are marked A-cycles.

The advantages of the regenerative cycle are well known and have been covered recently in numerous articles as applied to high

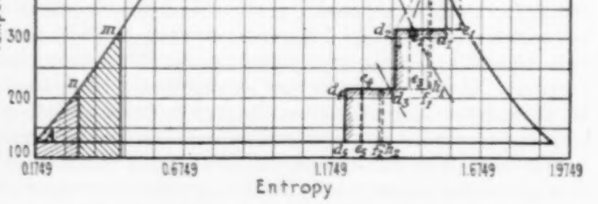


Fig. 1 Temperature-Entropy Diagram, 800 to 700 Deg. Fahr., S- and SR-Cycles

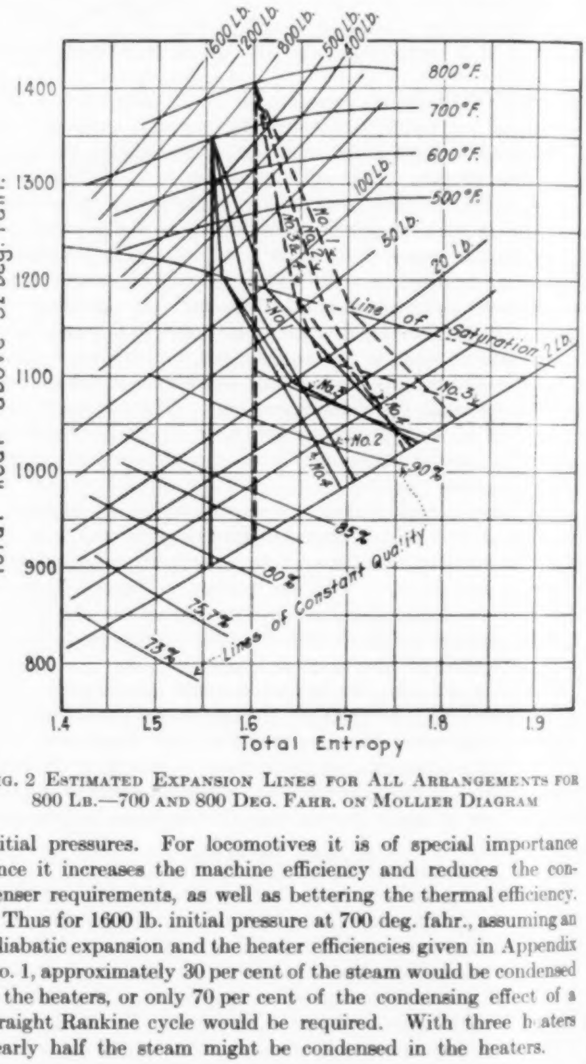


Fig. 2 Estimated Expansion Lines for All Arrangements for 800 Lb.—700 and 800 Deg. Fahr. on Mollier Diagram

initial pressures. For locomotives it is of special importance since it increases the machine efficiency and reduces the condenser requirements, as well as bettering the thermal efficiency.

Thus for 1600 lb. initial pressure at 700 deg. fahr., assuming an adiabatic expansion and the heater efficiencies given in Appendix No. 1, approximately 30 per cent of the steam would be condensed in the heaters, or only 70 per cent of the condensing effect of a straight Rankine cycle would be required. With three heaters nearly half the steam might be condensed in the heaters.

## Heat-Entropy and Temperature-Entropy Diagrams

In Figs. 1 and 2 the temperature-entropy and heat-entropy (or Mollier) diagrams are shown for 800 lb. pressure and 700 deg. fahr. and 800 deg. initial temperatures. Fig. 1 also shows a 100-deg. fahr. reheat effect. Fig. 1 gives a proportional value for the cycle, since when steam is withdrawn to the heaters the curve ceases to indicate the true state of the steam. By relocating the saturation curve an idea of the action can be approximated. On Fig. 2 no steam withdrawal has been indicated nor reheat effect shown. In addition to the adiabatic, other expansion lines have been drawn to show the estimated results for the different arrangements of driving. These lines are of course merely indicative. It should be kept in mind that with the regenerative effects considered, only the steam going to the condenser would follow the complete expansion shown. Other

portions of the steam would be drawn off at various points of the expansion to be condensed in the heaters. It should be noted that during the higher pressure and temperature range the expansion indicates a better efficiency. This for turbines is due mainly to the smaller moisture content and for cylinder expansions to the reduced exhaust and throttling loss. Thus all steam

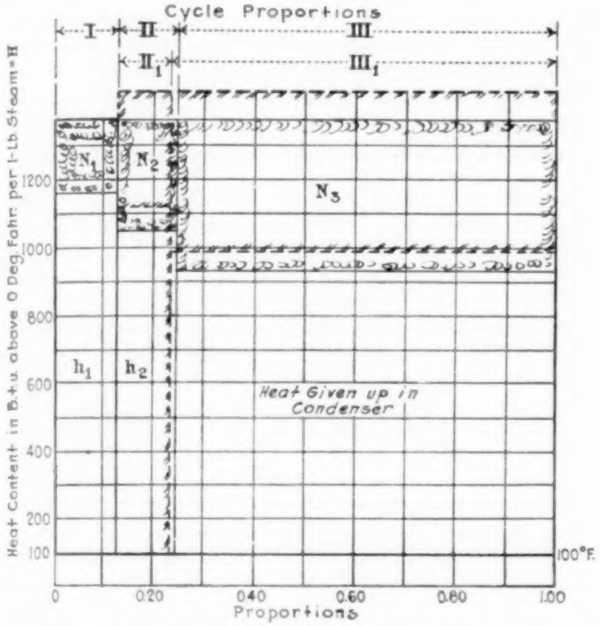


FIG. 3 COMPARATIVE HEAT DISTRIBUTION. FULL LINES—S-CYCLE, 800 LB., 700 DEG. FAHR., AND TWO HEATERS. DOTTED LINES —SR-CYCLE, 800 LB., 700 DEG. FAHR., AND TWO HEATERS

that is condensed in the heaters can be more efficiently used than that going to the condenser.

The expansion lines on the Mollier diagram are often spoken of as the characteristic lines for a steam-driven machine. They do not show the efficiency since they do not give the proportions between radiation, leakage, and friction losses. However, they indicate the efficiency when leakage is low, since radiation for any machine can be estimated closely.

In the diagrams shown the action of the steam has been taken as a whole. It can more simply and correctly be considered as divided up into several parallel cycles. Thus the steam expanding to each heater or the condenser pressure would form individual Rankine cycles simple to consider. Fig. 3 represents the heat and power effects of a group of parallel cycles. It is simply a block area with the ordinates indicating the total heat per unit quantity of steam and with the abscissas showing the proportional amounts. It might be called a heat-distribution diagram. Thus the ordinates are marked off in B.t.u. per pound of steam and the abscissas in percentages. I shows the relative per cent of steam condensed in heater No. 1, II that condensed in heater No. 2, and finally III the proportion that goes to the condenser.

$N$ is used to indicate the heat drop and $h$ the heat in the exhaust to the heaters. The base line is taken at 100 B.t.u., or the approximate heat content per pound of the cooled condenser condensate above 0 deg. fahr. The total $N$ areas divided by the total $H$ above the base line less the $h$ area would give perfect efficiency for the conditions assumed. An approach to actual efficiencies can be obtained from this plot. Thus by deducting from the $N$ areas the losses due to radiation, leakage, and friction, and from the $h$ areas the losses due to heater radiation and ventage, and transferring the drainage loss from $h_1$ to $h_2$ and from $h_2$ to the condenser loss, the actual efficiencies will be approximated. This approximation will not allow for leakage and friction losses from $N_1$ and $N_2$ being utilized in $h_1$ and $h_2$, respectively, and acting to change the proportions I, II, and III.

The plot of Fig. 4 was prepared to bring out more clearly the variance in condenser effect with increased pressure and regenerative effect. Thus the dotted lines show the area for 400 lb. pressure and 700 deg. superheat with a single heater. The full lines indicate the values for 1600 lb. and 700 deg. with three heaters in series. With engine drive, added heating effects may sometimes be advantageous to reduce the exhaust volume to the condenser.

### CYCLE EFFICIENCIES

The term "cycle efficiency" is taken to apply to the ratio between the total adiabatic heat drops and the net heat given to the steam by the boiler. Thus these efficiencies include allowance for heater efficiencies. The methods of figuring these efficiencies and the figures they are based on are given in Appendix No. 1. The curves of Figs. 5 and 6 show the results obtained for the different initial temperatures and cycles with the pressure varying between 400 and 1600 lb. In all cases a rapid increase in efficiency is indicated up to approximately 800 lb. pressure, and a smaller rate of increase above.

Relatively small changes in heater locations as well as heater efficiencies will change the cyclic efficiencies. The locations assumed are approximately correct for the best efficiency, but are based partly with the idea of securing the best heating effect for the minimum heating surface. The location of the reheat effect has been taken as coincident with the highest-pressure bleeding point.

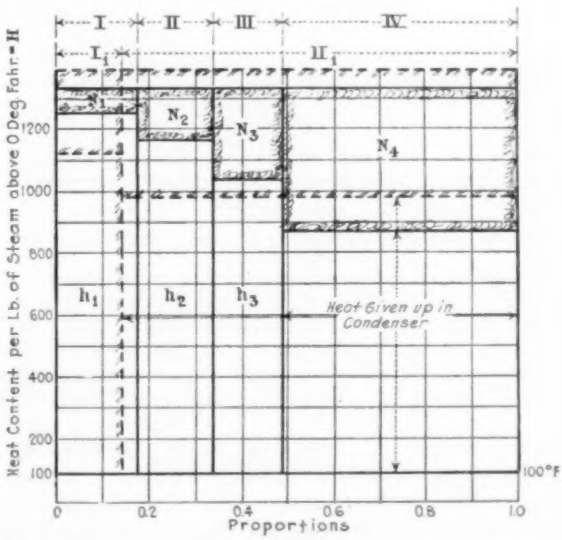


FIG. 4 COMPARISON OF HEAT EFFECTS. FULL LINES—S-CYCLE, 1600 LB., 700 DEG. FAHR., 3 HEATERS. DOTTED LINES—S-CYCLE, 400 LB., 700 DEG. FAHR., ONE HEATER

### AUXILIARY REQUIREMENTS

From these cyclic efficiencies the net thermal efficiencies for all the arrangements are computed. The first step consists of allowing for the auxiliary requirements. Fig. 7 gives the auxiliary requirements for each pound of steam generated. The requirements are given in B.t.u. and represent the power calculated as required at the shaft of the fan, pump, etc., as the case may be. The efficiencies assumed and the methods of

computing are given in Appendix No. 2. All requirements were found to vary about directly with the pressure, or as a straight line. The only auxiliary that shows an increased power for increasing pressures is the boiler-feed pump. The increase in power for this item counterbalances all other decreases so as to produce a large total increase. Draft requirements and

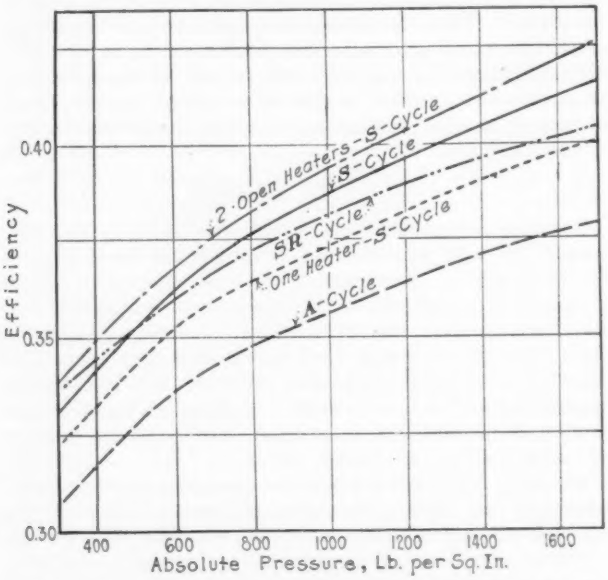


FIG. 5 COMPARISON OF CYCLE EFFICIENCIES, 700 DEG. FAHR. INITIAL STEAM TEMPERATURE

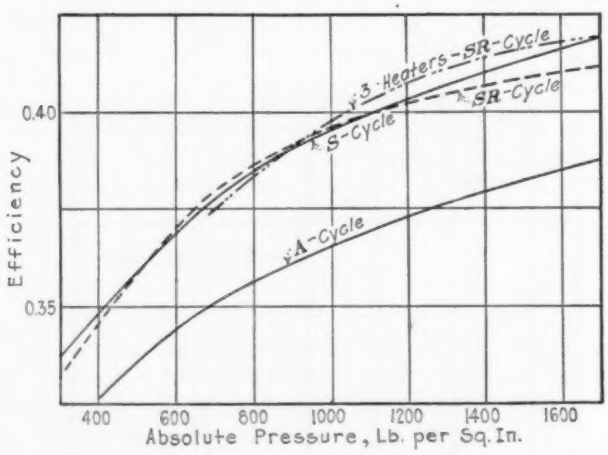


FIG. 6 COMPARISON OF CYCLE EFFICIENCIES, 800 DEG. FAHR. INITIAL STEAM TEMPERATURE

condenser-auxiliary requirements would vary normally with the cycle as well as with the pressure. To avoid too much complication an average for the various cycle requirements was assumed for each pressure. A total draft head of six inches of water was assumed for average loading with the type of boiler and furnace considered. For the condenser the principal power requirement would be for air blast. With the design suggested the train motion would partly furnish the head at high speeds. The fan was, however, considered as supplying the total air flow.

With the first and third arrangements a separate turbo-generator is proposed to furnish power for the motor-driven auxiliaries, and its machine and transmission efficiencies are shown in Figs. 8 and 10. With arrangements 2 and 4 the transmission efficiency is taken the same as for a separate turbo-generator, and the machine efficiency the same as for the main drive. It is probable that the induced-draft fan and condenser air pump might need to be steam-actuated. For convenience they have been considered as motor-driven. Where steam is used the net efficiency might even be higher if the steam were bled off at some intermediate pressure.

Total B.t.u. requirements were thus found for the different arrangements and cycles, and were taken from the adiabatic heat drops to obtain modified cyclic efficiencies for each arrangement. From these values the net thermal efficiencies were obtained by including the boiler, transmission, and machine efficiencies for each arrangement.

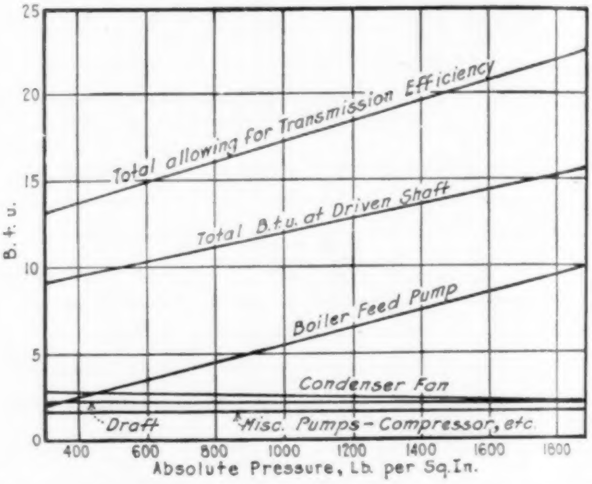


FIG. 7 AUXILIARIES—REQUIREMENTS FOR POWER IN B.T.U. POWER EQUIVALENT REQUIRED PER LB. OF STEAM GENERATED. ALL VALUES FOR AVERAGE LOAD ONLY

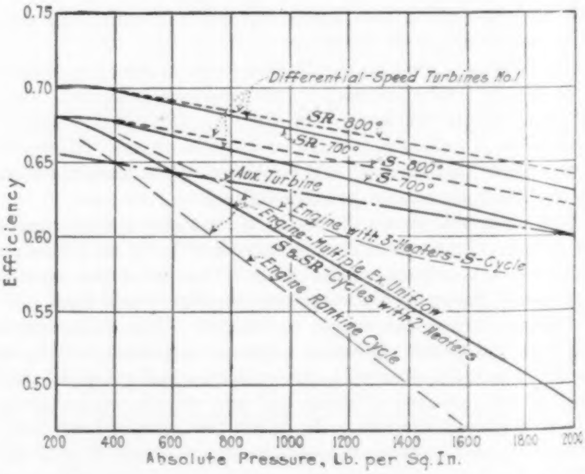


FIG. 8 MACHINE EFFICIENCIES FOR ARRANGEMENTS 1 AND 3 AND AUXILIARY TURBINE

## MACHINE EFFICIENCIES

The term "machine efficiency" is taken here to indicate the ratio between the adiabatic heat drop for any steam expansion and the power delivered by the steam-driven unit. The power delivered is taken at the shaft for turbines and at the axle or driving wheels for engine drive. In the latter case only the friction of the crankshaft bearings should be included.

Figs. 8 and 9 show the machine efficiencies estimated for the different arrangements, pressures, and cycles. These efficiencies are indicated as varying in a straight line with the pressure.

What efficiencies can actually be realized will depend somewhat on the designs that may be evolved. These designs always will be compromises in which efficiency will be sacrificed to some extent. It s believed that the values set down are conservative. The efficiencies are intended to represent what may be attained for average loading, or between one-half and three-fourths of full load. At the lower pressures the values were taken from guarantees and tests on units approximating the power requirements, and deductions were made to allow for the limitations probable, due to the special service. With turbines, loading below ratings means normally operating at a reduced throttle pressure unless by-pass governors are depended on to attain rating. In this latter case maximum efficiency would occur somewhere below rating.

The slopes of the turbine-efficiency lines for the higher pressures are not as steep as have been given in other published articles for the Rankine cycle. This is due to two modifications introduced. Thus, as pointed out previously and as shown in Fig. 4, when the pressure increases, with the cycles used here, a greater portion of the steam is condensed in the heaters or in the range of higher efficiency. Thus the influence of moisture in reducing total efficiency is lessened. This in itself should about account for the difference. In addition, it is assumed that a considerable proportion of the moisture may be drained off to the heaters with the bled steam. This assumption is based on the observation that the moisture accumulates near the periphery of the turbine as soon as condensation commences, due of course to centrifugal force. Since the values for machine efficiency do not include heater efficiencies, except for the drop in pressure in the steam flow, all efficiencies would be combination Rankine effects.

Higher initial superheat and reheat are considered as increasing the attainable turbine efficiency, due of course to reducing the moisture content. The differential would, however be reduced somewhat since additional superheat and reheat would also reduce the heater condensation with the heater locations assumed.

With arrangement No. 1 lower efficiencies were taken than for a constant-speed machine, since an average load would naturally occur at a reduced or less efficient speed. It is probable that for freight service where the highest loads are often at low speed the efficiencies set down may be high for average loading. It is also probable that smaller units would normally be used for No. 1. Thus for large locomotives at least two separate drives would be required to distribute the driving stresses.

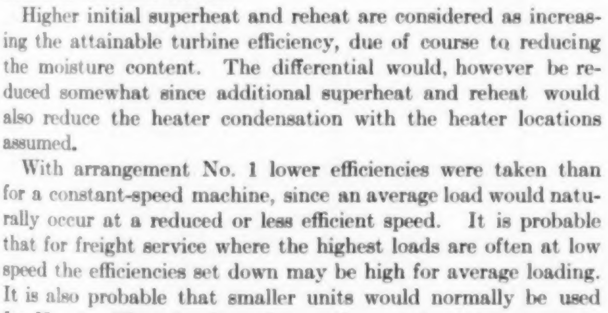


Fig. 9 Machine Efficiencies for Arrangements 2 and 4

Arrangement No. 2 is assumed as one constant-speed turbine driving a direct-current generator through gears. Thus the turbine could be made as best suited for efficiency, aside from the space limitations.

At present, engine-driven locomotives have a machine efficiency of approximately 72 per cent for simple engines at 200 lb. pressure, 550 deg. fahr. temperature, and approximately 20 lb. exhaust pressure. Compound engines operating on 300 to 350 lb. and 650 deg. fahr. show about 70 to 71 per cent machine efficiency. These figures are a little uncertain as nearly all locomotive tests lump the steam consumption for auxiliaries with that used for the main drive. Superheat has no effect on engine machine efficiency as here expressed since moisture does not lessen it. The main loss would be, with engine drive, the restricted expansion and throttling exhaust at the low exhaust pressures assumed here. This loss would be reduced considerably by the use of the uniflow-exhaust principle. In fact, simple uniflow engines show about the same machine efficiency with

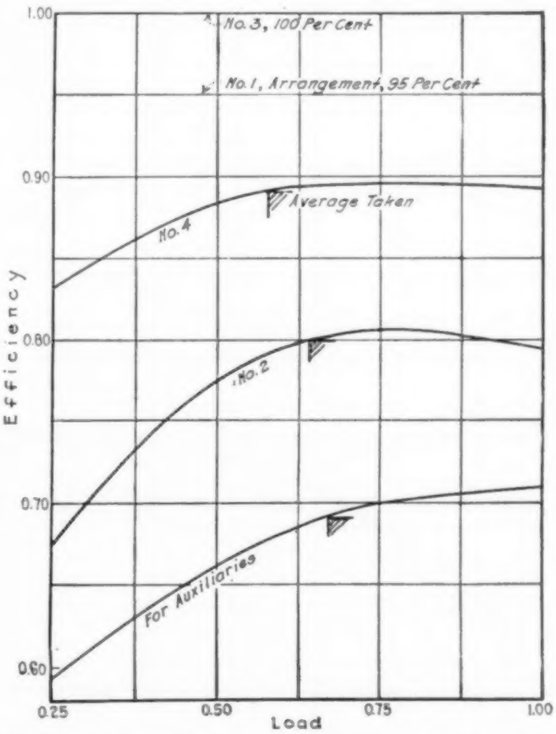


Fig. 10 Transmission Efficiencies for the Different Arrangements

2 lb. back pressures for 200 lb. as standard simple engines for 20 lb. This is due to reduced cylinder condensation, reduced clearance, and a reduction in the exhaust throttling loss. Any uniflow cylinders used for locomotives would have to be modified to take care of excessive compression and to give a suitable starting acceleration.

As the pressure is increased the relative total expansion-rate increase is not entirely in proportion to the steam-volume change due to the increased condensation. It further will be reduced with the cycles here considered by the heater condensation. Thus at 1600 lb. pressure and 700 deg. fahr. nearly 30 per cent of the steam will be condensed in the heaters or will operate at a fairly high machine efficiency. This point is clearly brought out in Fig. 8 where the machine efficiency for a Rankine cycle and a three-heater cycle are shown in addition to the curve for the two-heater-engine arrangement. In addition, the decreasing initial volume of the steam with the increase in pressures will permit the design of cylinders to be partially proportioned to suit the increased expansions. All these features were considered carefully in determining the machine efficiencies shown. The slope of the curve for engine drive shown in Fig. 8 probably could be bettered with a careful design.

Thus while the initial value of 69 per cent for 200 lb. is high for a Rankine cycle and present equipment used condensing, it proves out as conservative with a regenerative cycle and a uniflow drive suited for economy.

In arrangement No. 4 the machine efficiency would be a com-

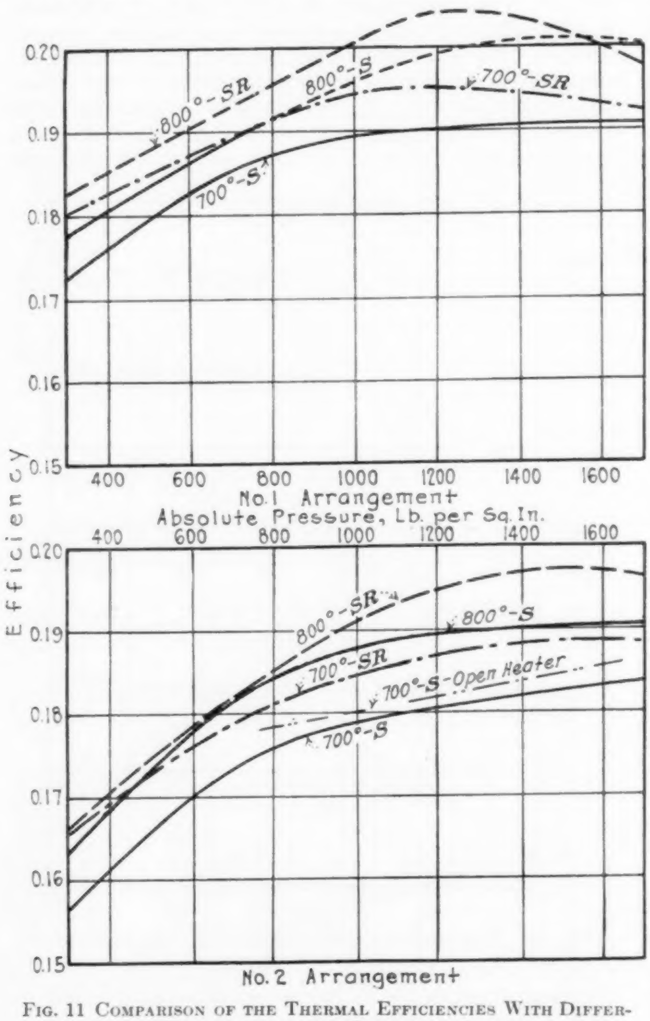


Fig. 11 Comparison of the Thermal Efficiencies With Different Initial Temperatures and Cycles for Arrangements Nos. 1 and 2

bination of engine efficiency at the high pressures and turbine efficiency at the lower pressures. The engine efficiency is not considered as changing for the different cycles or superheats. The low-pressure turbine is considered as increasing in efficiency with reheat but as not varied for the initial superheat, since with either 700 or 800 deg. initial temperature and without superheat this turbine would operate in the saturated zone. With provision for drainage between the engine and turbine the moisture content in the steam flowing to the turbine should be approximately the same for either of the initial superheats assumed.

### Transmission Efficiencies

Transmission efficiencies for the various arrangements of drive and for the auxiliary high-pressure turbine are given in Fig. 10. No. 3 arrangement is direct acting, and as noted before has no separate transmission mechanism. No. 1 arrangement uses only a set of gears. A constant efficiency of 95 per cent has been assumed for the gear transmission. This value allows for some excess friction due to wear.

All electric drive has been taken as using direct current with a variable generator-voltage control, similar to the Ward Leonard control. This arrangement has worked out well with Diesel-electric drives. It provides high economy combined with a simplified control. In the fourth arrangement there would be a combination of direct drive and electric transmission. For convenience half the power has been considered as electrically transmitted.

In Appendix No. 3 are set down the itemized efficiencies on which the curves of Fig. 10 are based. It will be noted that a higher efficiency is set down for the motor and generator gear transmission than for the gear drive of No. 1 arrangement. This is due to the lower ratio of transmission, the constant speed for the generator, and the lower power rate for the motors. The auxiliary motors are assumed to be direct-current, shunt or compound-wound.

### Thermal Efficiencies

To summarize algebraically, the formulas below show the

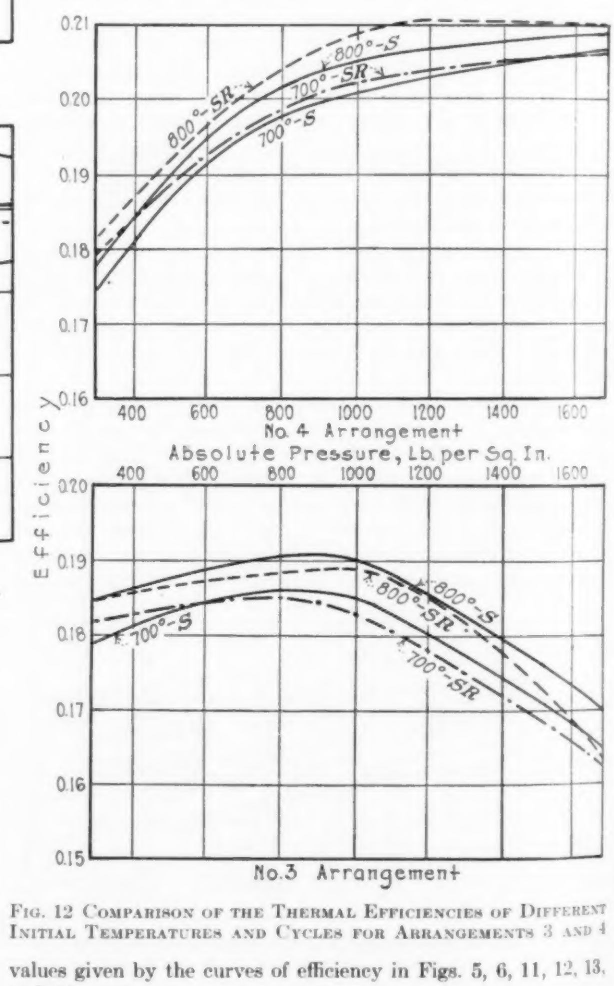


Fig. 12 Comparison of the Thermal Efficiencies of Different Initial Temperatures and Cycles for Arrangements 3 and 4

values given by the curves of efficiency in Figs. 5, 6, 11, 12, 13, and 14.

$$E_c = \frac{N}{H - h} \text{ cyclic efficiency, Figs. 5 and 6.}$$

$$E_t = \frac{N - n_r}{H - h} E_m\, E_a\, E_b, \text{ thermal efficiencies, Figs. 11-14.}$$

where

$N$ = total adiabatic heat drop from admission and reheat to the heaters and condensers

$H$ = total heat in the steam above 32 deg. fahr.

$h$ = total heat in the water at the high-pressure heater outlet, or boiler inlet, above 32 deg. fahr.

$n$ = heat equivalent of power required for the auxiliaries

$E_m$ = machine efficiency

$E_t$ = transmission efficiency

$E_b$ = boiler efficiency, taken at 85 per cent.

The curves of Figs. 11 and 12 illustrate the different efficiencies attainable with the different initial superheats and cycles for each arrangement. For arrangements 1, 2, and 4, which have turbines included, the SR-cycles give in general better results. With No. 3 arrangement the variance is of course relative to the cyclic variance, while with No. 4 the differences are small at the higher and lower pressures.

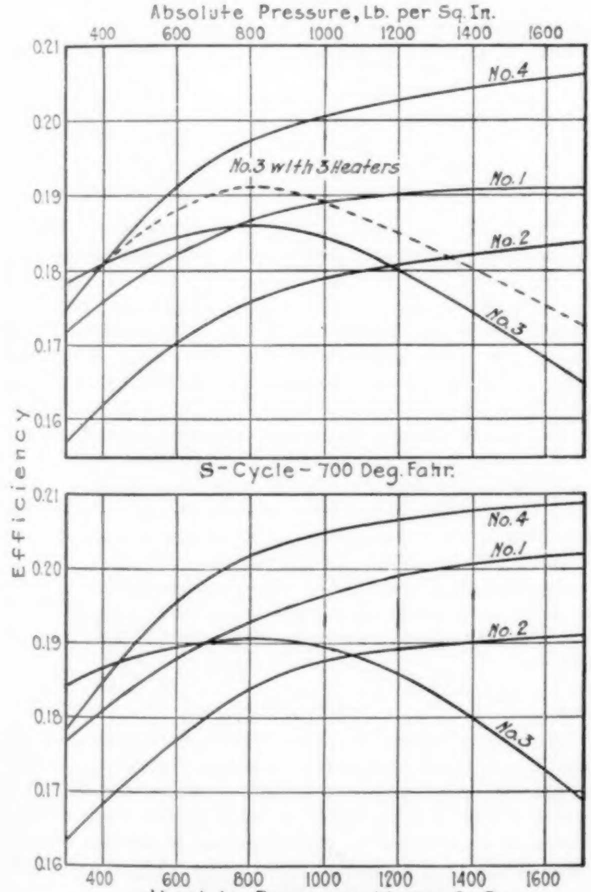


FIG. 13 COMPARISON OF THERMAL EFFICIENCIES FOR DIFFERENT ARRANGEMENTS OF DRIVE WITH THE S-CYCLE

Figs. 13 and 14 compare the efficiencies of all the arrangements for each different initial superheat and cycle. In all cases No. 4 arrangement stands out at the higher pressures above the rest. Apparently the increase in efficiency above 1200 lb. is too small to be attractive in any case. In fact, No. 3 arrangement shows a decrease from approximately 800 lb. Apparently unless the machine efficiency with engine drive could be improved over that estimated, it is improbable that it would pay to generate above 400 or 500 lb. with a complete engine drive. For further comparison, Fig. 13 shows a curve of estimated efficiencies for No. 3 arrangement with three heaters.

The advantages of the combination taken for No. 4 arrangement suggests that the use of a low-pressure turbine for driving the auxiliaries in No. 3 arrangement might improve the total efficiency considerably. The results seem to show, however, that the best all-around combination would be the No. 4 arrangement. No. 1 arrangement on average high speeds such as for through passenger service might be preferable due to the lower first cost. However, present experiences in power stations with gear transmission at the ratio that would be required would indicate that the maintenance for this arrangement might prove too high for economical operation. The trials on locomotives now in use should soon show whether this form of drive will wear.

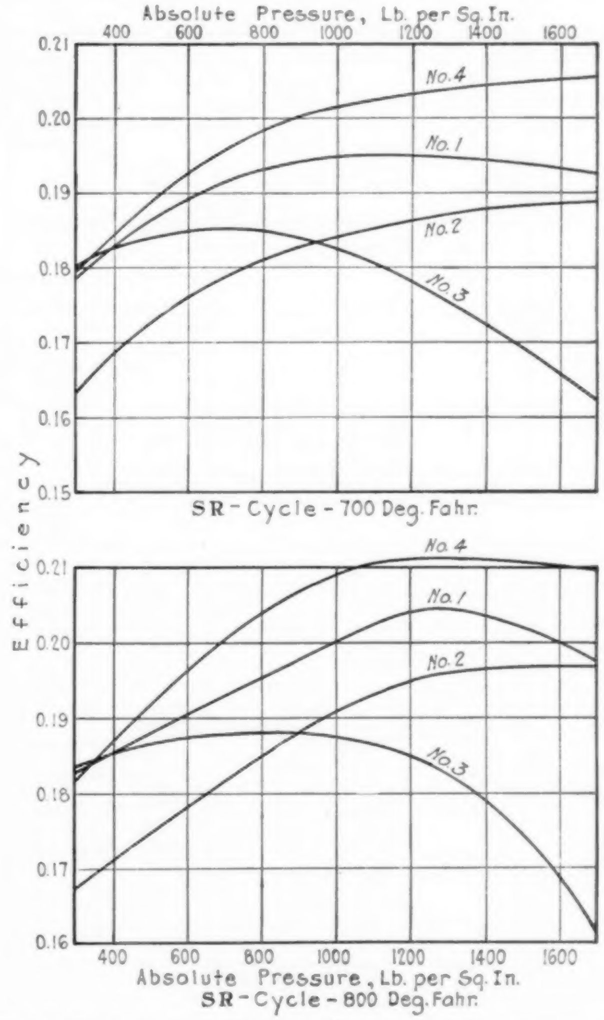


FIG. 14 COMPARISON OF THERMAL EFFICIENCIES FOR DIFFERENT ARRANGEMENTS OF DRIVE WITH THE SR-CYCLES

While No. 2 arrangement shows a lower average efficiency than either No. 1 or No. 4 arrangements, it has certain advantages that for some situations might compensate. Thus it would be possible to arrange the electric equipment so that it could be operated from a trolley or third rail when in an electrified zone. In addition it has an advantage over No. 1 arrangement in tractive characteristics, and over No. 4 arrangement in that the con-

densate would be entirely free from oil contamination. It is probable that the latter feature might allow for the use of open heaters, in which case there would be a possible increase in thermal efficiency.

### Value of Locomotives

Thermal economy as noted in the first part of this paper does not indicate directly the operating economy of a locomotive. For a large portion of the service it has, however, a definite bearing on the total economy. Thus the relative values of locomotives may be said to be determined primarily by the ratio between their average yearly capacity or ton-mileage and the cost of operation. The capacity of a locomotive for heavy freight service varies with its maximum tractive force, its power capacity, its proportional time in service, and its reliability of service.

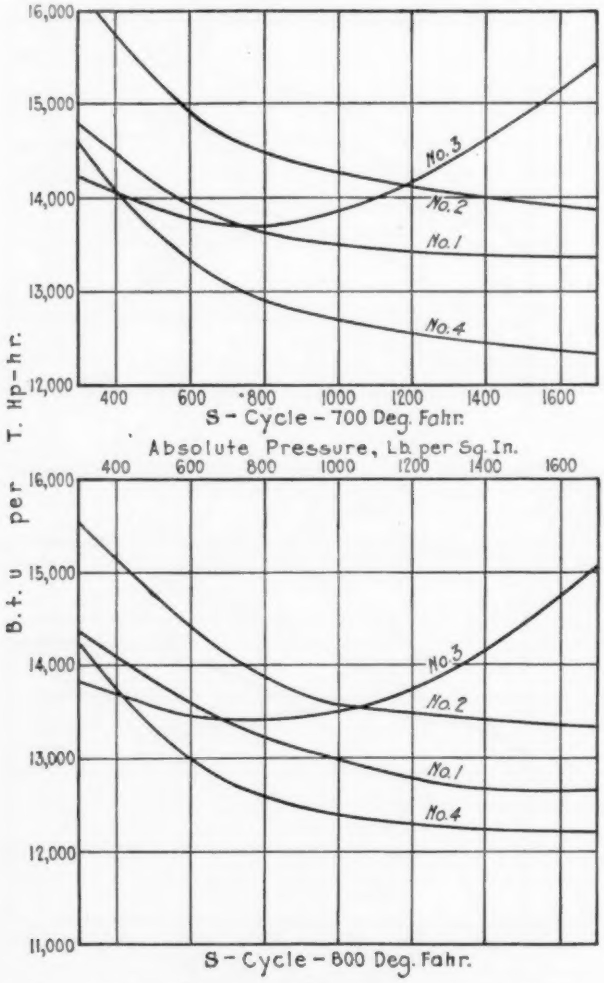


Fig. 15 B.t.u. Required per Tractive-Horsepower-Hour

For the normal speed of freight service, train resistance is nearly constant. Accordingly, an increase in power capacity will provide a nearly direct increase in speed. Or, in other words, the mile-tonnage capacity will be increased directly as the power capacity for any given train. At the same speed an increase in train tonnage would be needed to provide increased locomotive capacity. Increases in train tonnage require increased tractive force as well as increased power capacity. For present conditions it is assumed that the maximum economic train tonnage has been reached. Proportional time in service and reliability of service are matters to be determined by trial. The pressure of operation should not affect these items. The design proposed, with its absence from scale trouble, burnt grates, and its greater simplicity of boiler, should, however, show material improvement in both respects.

With power capacity directly varying as locomotive capacity, it has also been assumed that power capacity will directly depend on thermal efficiency. This would of course hold only for designs approximately the same. Of course the drive design, say a turbine or engine, would need to vary somewhat with the pressure. The boiler and combustion system could, however, be the same regardless of pressure for the type suggested. The efficiency of heat absorption will not enter into the question as long as it is considered constant. It is assumed of course that the best design has been selected. Then as the pressure changes the thermal efficiency will change. Since the thermal output of the boiler is constant, the power capacity must vary as the thermal efficiency. Accordingly the locomotive capacity for the service considered will vary for otherwise constant conditions nearly directly as the thermal efficiency.

Cost of operation of locomotives may be divided as follows:

| | | |
|---|---|---|
| 1 | Fixed charges | 20 per cent |
| 2 | Labor | 18 per cent |
| 3 | Maintenance | 20 per cent |
| 4 | Miscellaneous materials | 8 per cent |
| 5 | Fuel cost | 34 per cent |

This division is tentative and will vary for every difference in operating conditions. The first four items are not here considered as varying with the pressure. They will vary with the design in a greater degree. Fixed charges will vary somewhat, but it is anticipated that the cost will increase with value, though not at the same ratio. The fuel cost or fifth item is given as one-third of the total, which is a fair average for different conditions.

Accordingly, the total locomotive operating value would vary in a four-thirds proportion to its thermal efficiency. On this basis the curves shown in Fig. 17 have been set down. They show the variation in valuation between 350 lb. initial pressure and 1800 lb. for 700 deg. fahr. initial temperature and both the S- and SR-cycles. Only No. 4 arrangement is indicated.

Valuation of locomotives for heavy express passenger service would be on nearly the same basis, though there are other factors involved that would be somewhat different for each territory and run.

### First Cost

No attempt has been made in this paper to compare efficiencies with those attained by present standard locomotives, since the equipment estimated is so different. A comparison of first cost also is of dubious value. The present standard-pressure turbine-driven locomotives built in Europe are said to cost approximately twice the figure for standard construction. These locomotives, however, have been specially built, and it is probable that the cost cited is therefore no criterion of what would prevail if the new designs were built in quantities on a competitive basis. In the type of equipment considered in this article there should be a reduction in cost for parts of the equipment, especially so with a flash or non-water-line boiler such as is indicated in Fig. 18. The condenser proposed would also be much simpler than that used with the locomotives built in Europe.

Re-use of the condensate and better thermal efficiency would reduce the size of tender required. In view of these considerations an estimate of costs has been made (Table 1). This estimate can be compared with the cost of a heavy-duty freight locomotive of recent design equipped with all modern accessories

and built for 250 lb. pressure. The estimate is based on tractive-horsepower capacity and was made up for units of approximately 4000 tractive horsepower, which is about, if not above, the limit for standard units. Costs are estimated for standardized construction, or no allowances are made for special design, and workmanship. On this basis it is felt that the estimates are as nearly correct as can be made without designs.

TABLE 1 ESTIMATED COST OF SUPER-PRESSURE LOCOMOTIVES PER TRACTIVE HORSEPOWER

| | Steam pressures, lb. per sq. in. | | | |
|---|---|---|---|---|
| | 400 | 800 | 1200 | 1600 |
| Arrangement No. 1...... | $30.00 | $31.00 | $33.00 | $36.00 |
| Arrangement No. 2...... | 47.00 | 48.00 | 49.00 | 51.00 |
| Arrangement No. 3...... | 30.00 | 31.50 | 35.00 | 38.00 |
| Arrangement No. 4...... | 40.00 | 41.00 | 42.00 | 43.50 |
| Arrangement No. 4-R.... | 41.50 | 42.50 | 43.00 | 45.00 |

Standard three-cylinder locomotives, 250 lb., $30.00 per tractive horsepower.

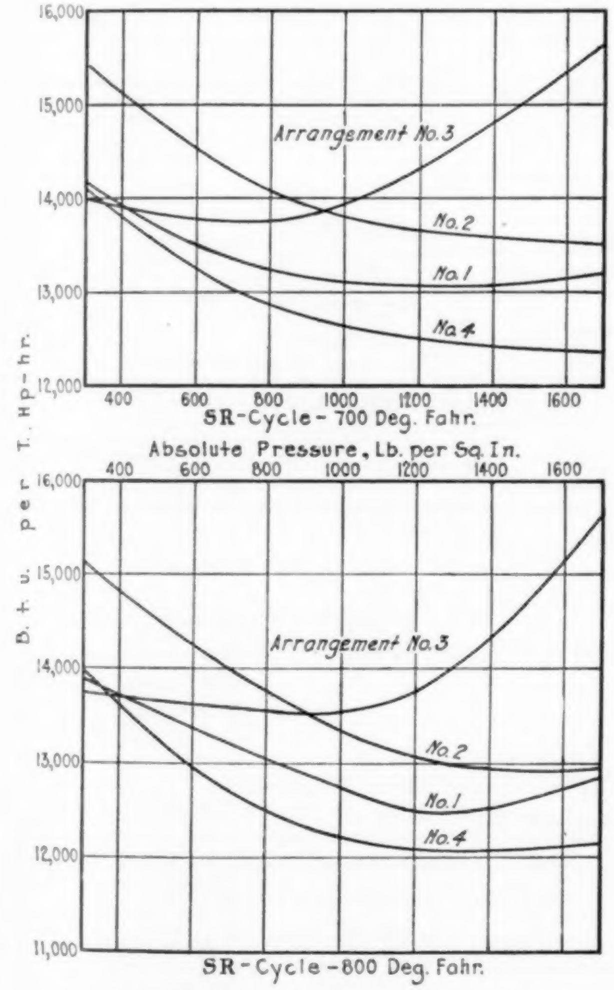


FIG. 16 B.T.U. REQUIRED PER TRACTIVE-HORSEPOWER-HOUR

Increasing pressure only slightly increases the cost except for No. 3 arrangement, the economy of which decreases above 800 to 1000 lb. No inclusion for reheat is made except in an added estimate for No. 4 arrangement marked 4-R. All costs given include the tender.

### Conclusion

The curves of efficiency given can apply to any form of steam generation and with modifications to any form of drive. In setting forth as requisite the types of equipment suggested, safety and practical cost limitations were the main considerations. It is understood that the success of a super-pressure locomotive such as suggested or of any other construction depends on the correct selection and design of several essential details. At the present time it is believed that all the essentials can be solved due to recent advancements in knowledge and practice. It is felt that to obtain the best solution with respect to some of the features involved, tests and operating trials are needed.

## Appendix No. 1

THE proportions of steam discharged to heaters and condensers are taken as I, II, III, etc., respectively.

The heater loss by radiation and ventage plus one is taken as $f$, or for a 5 per cent loss as assumed, $f = 1.05$ in all cases.

Thus

$$\text{I} = \frac{f_1 h_1}{H_1 Q_1} \quad \text{for closed heaters}$$

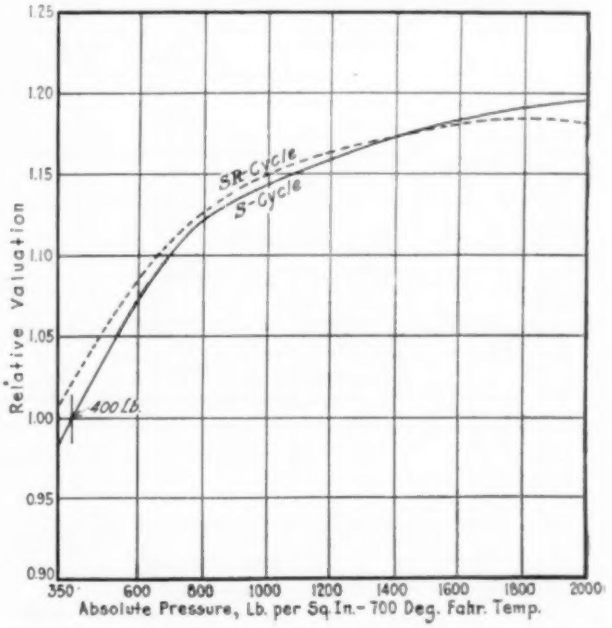


FIG. 17 No. 4 ARRANGEMENT VARIANCE IN LOCOMOTIVE VALUATION BASED ON THERMAL EFFICIENCY

$$\text{II} = \frac{f_2(h_2 - \text{I}h_1)}{H_2 Q_2} \quad \text{etc.}$$

$$\text{III} = \frac{f_3(h_3 - h_2)(\text{I} + \text{II})}{H_3 Q_3} \quad \text{etc.}$$

$$\text{I} = \frac{f_1 h_1}{(H_1 + h_1)Q_1} \quad \text{for open heaters}$$

$$\text{II} = \frac{f_2 h_2(1 - \text{I})}{(H_2 + h_2)Q_2}$$

$$\text{III} = \frac{f_3 h_3[1 - (\text{I} + \text{II})]}{(H_3 + h_3)Q_3} \quad \text{etc.}$$

Where $h$ = heat given to one pound of feedwater in the heater

$H$ = heat in each pound of steam flowing to the heater less the heat per pound of liquid at the heater discharge

$Q$ = quality of the steam flowing to the heater.

In the case of the closed heaters no allowance is made for any heat being given up by the condensed steam below the discharge-water temperature. In well-designed heaters in good condition the drainage should be well below the temperature of the discharge water. In usual practice it is very close to the maximum water temperature.

This heat is considered as used in the heater of lower pressure or for the lowest-pressure heater as discharging to the condenser.

Temperature of heater discharge is taken for closed heaters as 10 deg. fahr. below saturated steam temperature, and for open heaters as 5 deg. fahr. lower.

As here used, $h$ should not be confused with $h$ as used to represent total heat in feedwater at highest-temperature-heater discharge, in the formulas for $E_c$ and $E_t$ given in the paper.

In all cases the pressures given are absolute and the condenser pressure is taken at 2 lb. or 126.1 deg. fahr.

In figuring heater effects the temperature of the supply water was taken at 100 deg. fahr. or 26.1 deg. below condenser steam temperature.

Subscripts indicate heat effect. Thus $h_1$ refers to the heat given to the feedwater in No. 1 or the highest-pressure heater. For two heaters III indicates the proportion of steam entering the condensers. Values I, II, and III include steam and such moisture as would be present due to adiabatic expansion.

*Reheat.* When reheat is added the moisture content in the steam is considered as being evaporated and the total mixture raised to superheated steam at 100 deg. fahr. above the saturated-steam temperature. It is anticipated that a portion of the moisture may be drained off, which would very slightly increase the efficiency, but no allowance is made.

All pressures given are absolute and all temperatures fahrenheit. The temperature of the feedwater supply is taken at 100 deg. fahr. for all cycles, including the Rankine or A-cycle.

TABLE 2 TEMPERATURES OF STEAM TO HEATERS IN DEG. FAHR.

| Steam temperature cycle | Heater No. | Pressure, lb. per sq. in. 400 | 600 | 800 | 1200 | 1600 |
|---|---|---|---|---|---|---|
| 700 deg. S = Cycle | 1 | 294.8 | 306.6 | 317.0 | 327.7 | 358.4 |
| | 2 | 209.6 | 213.0 | 216.3 | 228.0 | 237.8 |
| 800 deg. S = Cycle | 1 | 259.3 | 300.0 | 317.0 | 327.7 | 358.4 |
| | 2 | 193.2 | 209.6 | 216.3 | 228.0 | 237.8 |
| 700 deg. SR = Cycle | 1 | 294.8 | ..... | 317.0 | 327.7 | 358.4 |
| | 2 | 209.6 | ..... | 216.3 | 228.0 | 237.8 |
| 800 deg. SR = Cycle | 1 | 259.3 | 285.8 | 317.0 | 327.7 | 358.4 |
| | 2 | 193.2 | 202.0 | 216.3 | 228.0 | 237.8 |
| 700 deg. S = Cycle | 1 only | 228.0 | ..... | 242.2 | 254.0 | 260.9 |

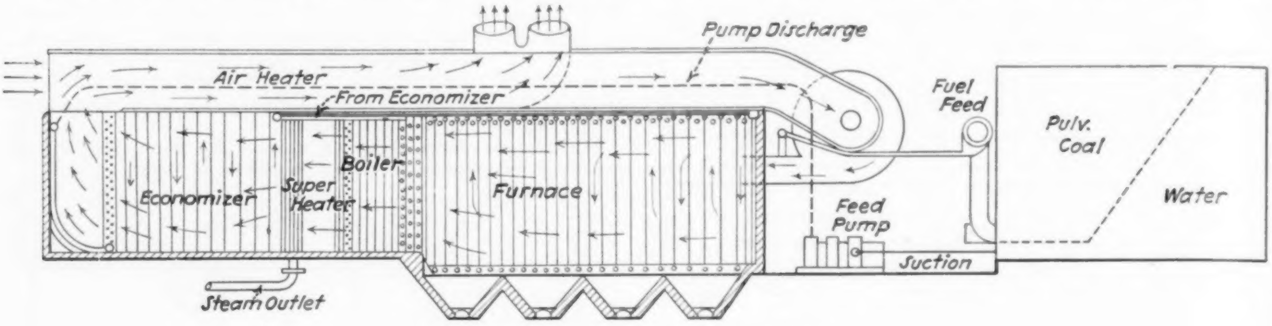


FIG. 18 SUGGESTED BOILER ARRANGEMENT

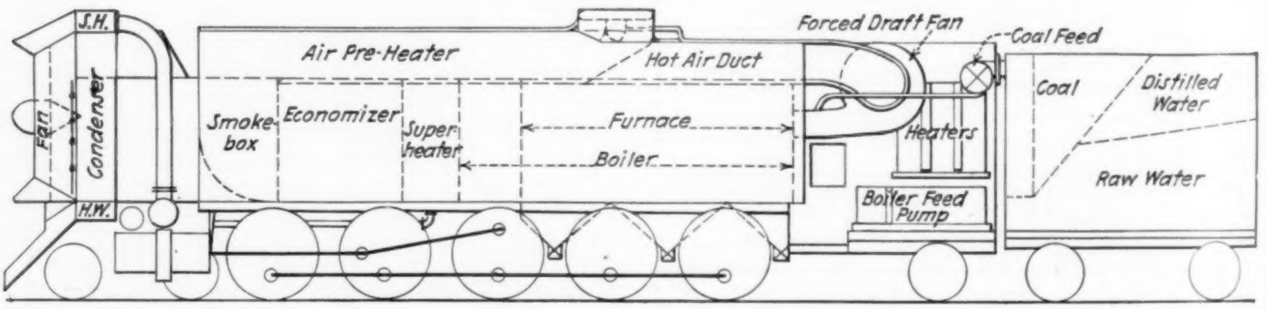


FIG. 19 ARRANGEMENT OF No. 3 DRIVE

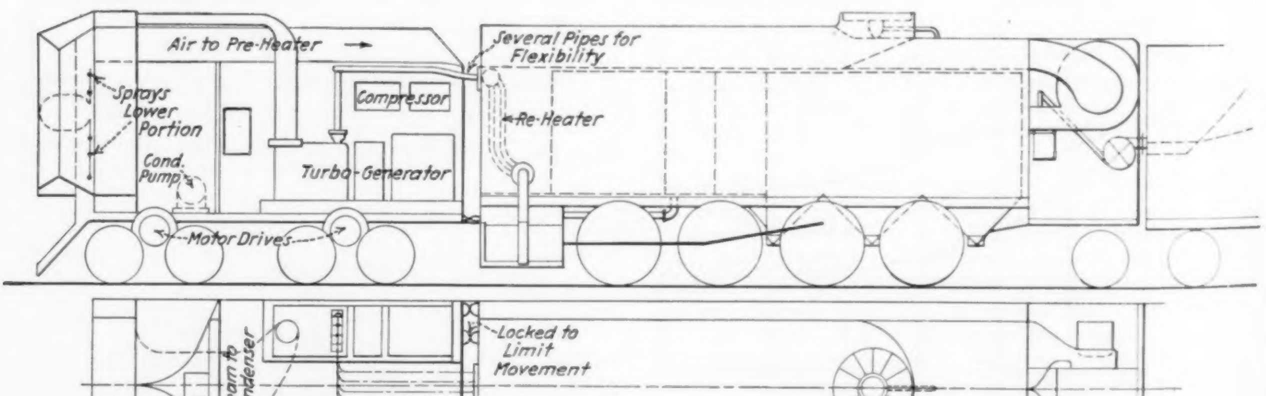


FIG. 20 ARRANGEMENT OF No. 4 DRIVE

## Appendix No. 2

### Boiler-Feed Pump

$$\text{B.t.u. per pound} = \frac{PV \times 144 \times 42.416}{33000 \times 0.60} = 0.00497\,P, \text{ say} = 0.005\,P$$

where $P$ = boiler pressure plus pressure drop through piping and boilers, lb. per sq. in.

$V$ = volume in cu. ft. of 1 lb. of water at suction temperature, say, 100 deg. fahr. = 0.01615. With open heaters $V$ would average higher and the pump efficiency would be lower, but the average quantity of water pumped would be less.

TABLE 3

| Boiler pressure, lb. per sq. in. | Average pressure drops, lb. per sq. in. | Average B.t.u. power equiv. |
|---|---|---|
| 400 | 100 | 2.5 |
| 800 | 100 | 4.5 |
| 1200 | 100 | 6.5 |
| 1600 | 100 | 8.5 |

### Condenser Auxiliary

The condensate pump and air pump are rather small items and have been included among the miscellaneous items.

The work of the fan would vary with the initial temperature and cycle as well as the pressure. An average of the values for each pressure is assumed. This makes the requirements set down for 700 deg. and the *S*-cycle slightly high and for 800 deg. and the *SR*-cycle slightly low.

$$\text{B.t.u. power equiv.} = 0.3175\,W$$

where $W$ = lb. of air per lb. of steam.

Atmospheric temperature = 70 deg. fahr.

Efficiency of fan = 55 per cent.

Static head, average load, = 2 in. of water.

$$W = \frac{H \times \text{III}}{80}$$

where $H$ = heat in each pound of steam entering the condenser above 120 deg. fahr.

III = per cent of total steam flowing to the condenser.

The air at 70 deg. is assumed 60 per cent humidity.

The discharge temperature of the air is assumed to be 120 deg. fahr., with a humidity of 95 per cent.

Then 1 lb. dry air, 70 deg. to 120 deg. fahr. = 12.5 B.t.u.

Evaporation of 0.07185 lb. of water = 69.6 B.t.u.

Raising temp. of 0.07185 lb. of water to 120 deg. fahr. = 3.6 B.t.u.

Total heat absorption per lb. of air = 85.7 B.t.u.

Take . . . . . . . . . . 80

TABLE 4 WEIGHTS OF AIR PER POUND OF STEAM

| Temperature and cycle | Absolute steam pressures, lb. per sq. in. 400 | 800 | 1200 | 1600 |
|---|---|---|---|---|
| 700 deg. fahr. — S | 8.60 | 7.84 | 7.35 | 6.51 |
| 700 deg. fahr. — RS | 9.16 | 8.55 | 8.275 | 7.65 |
| 800 deg. fahr. — S | 9.31 | 8.1 | 7.51 | 6.9 |
| 800 deg. fahr. — RS | 9.745 | 8.65 | 8.35 | 7.75 |
| Average | 9.204 | 8.285 | 7.871 | 7.202 |
| B.t.u. | 2.92 | 2.635 | 2.49 | 2.28 |

### Draft

With 85 per cent boiler efficiency, 6 in. of water per sq. in. average static head, 400 deg. fahr. average temperatures of air and gas through blowers, blower efficiency taken as 60 per cent and weight of gases and air averaged at 15.5 lb. per pound of coal.

With coal at 13,500 B.t.u. per lb., 11,500 B.t.u. to steam per lb. of coal.

$$\text{B.t.u. per lb. of coal} = \frac{V \times 144 \times 6 \times 42.416}{27.7 \times 33{,}000 \times 0.60} = 0.0114 \times 6 \times V$$

$V$ for 15.5 lb. and 400 deg. fahr. = 337

B.t.u. power equiv. = 23.06

| | Absolute steam pressures, lb. per sq. in. 400 | 800 | 1200 | 1600 |
|---|---|---|---|---|
| Lb. of steam, average, for different initial temperatures and cycles, per lb. of coal = | 9.75 | 10.11 | 10.24 | 10.7 |
| B.t.u. per lb. steam = | 2.36 | 2.28 | 2.25 | 2.15 |

TABLE 7 SUMMARY, B.T.U. FOR AUXILIARIES

| Pressure, lb. per sq. in. | 400 | 800 | 1200 | 1600 |
|---|---|---|---|---|
| Boiler-feed pump | 2.5 | 4.5 | 6.5 | 8.5 |
| Condenser | 2.92 | 2.635 | 2.49 | 2.28 |
| Draft | 2.36 | 2.28 | 2.25 | 2.15 |
| Small pumps and miscellaneous | 1.7 | 1.6 | 1.5 | 1.4 |
| Total | 9.48 | 11.015 | 12.74 | 14.33 |

A straight-line variance was assumed for all cases since the results indicated the approximate correctness of that assumption.

## Appendix No. 3

### Transmission

*No. 1 Arrangement—Geared Turbine Drive.* Tests and operation of reduction gearing for powers of from 1000 to 6000 horsepower, and reduction from 15 and 25 to 1 show an average of 97 to 98 per cent efficiency when in perfect condition for stationary drive. When wearing begins the efficiency reduces. For the conditions and service 95 per cent was assumed as a probable average.

*No. 2 Arrangement—Turbo-Generator with Motor Drive.* Generator-voltage speed control, direct current, turbo-generator drive through reduction gears.

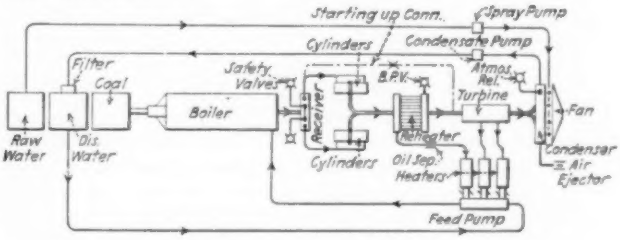


Fig. 21 Diagram of Connections, No. 4 Arrangement

| Loads | 1/4 | 1/2 | 3/4 | full |
|---|---|---|---|---|
| Gearing and generator | 87.00 | 92.0 | 93.0 | 92.0 |
| Motor | 80.00 | 87.0 | 89.5 | 89.0 |
| Motor gearing | 97.00 | 97.0 | 97.0 | 97.0 |
| Total | 67.50 | 77.5 | 80.5 | 79.5 |

*No. 3 Arrangement—Engine Drive Direct Acting.* Transmission 100 per cent efficient.

*No. 4 Arrangement—Engine.* High-pressure and low-pressure turbo-generator.

| | | | | |
|---|---|---|---|---|
| Half load, per cent | 100 | 100 | 100 | 100 |
| Half load, per cent | 66.5 | 76.5 | 79.5 | 78.5 |
| Total average | 83.25 | 88.25 | 89.75 | 89.25 |

Auxiliary Drive, turbo-generator motor:

| Loads | 1/4 | 1/2 | 3/4 | full |
|---|---|---|---|---|
| Turbo-generator gears | 97 | 97 | 97 | 97 |
| Generator | 82 | 85 | 87 | 88 |
| Motors | 75 | 80 | 83 | 83 |
| Total average | 59.5 | 6[illegible] | 70 | 71 |

When the auxiliary generator is on the main shaft the same efficiency of transmission is assumed as for the separate turbo-generator drive.

## Discussion

Lawford H. Fry.[2] The writer has read and heard Mr. Taggart's paper with much interest. In reading it there came to his mind a text which, if memory serves accurately, runs: "Without vision the spirit dieth." It seems to the writer that Mr. Taggart has given us a very interesting vision of what is possible for the steam locomotive of the future. It is a brilliant conception of what we may yet see. Of course we all realize that between conception and independent life there must come a difficult period of considerable length. Before the economies foreshadowed take shape there are many problems of design and construction to be solved, and probably it will be some time before Mr. Taggart's arrangement No. 4 is in active operation.

The economies proposed have been shown to be possible in stationary practice, but when they are to be obtained within the restricted limits allowed the locomotive designer, the difficulties of realization are increased greatly.

[2] Metallurgical Engineer, Standard Steel Works Co., Burnham, Pa. Mem. A.S.M.E.

One feature in particular has caught the writer's attention. Mr. Taggart figures on a boiler efficiency of 85 per cent. This requires a very high efficiency of combustion of the fuel—probably 95 per cent or better. Now, efficiency of combustion is largely dependent on the volume provided for combustion. The paper does not give any dimensions, but by a rough process of scaling it is estimated that the firebox is approximately 8 ft. in diameter and 16 ft. long. This gives about 800 cu. ft. of combustion volume. An output of 4000 horsepower at 1 lb. of coal per horsepower-hour will require the production of 50,000,000 B.t.u. per hour, or about 63,000 B.t.u. per cu. ft. per hour. Such concentrated heat production has been obtained in a few cases in stationary practice, but much lower rates are usual, and unless unusual precautions are taken difficulty with ash and slag removal will be encountered.

L. K. Sillcox.[3] The successful introduction of the high-pressure steam locomotive depends upon a complete, clear, and correct exposition of every known fact surrounding the subject in all of its phases. Mr. Taggart deserves every commendation for the manner in which he has handled the involved problem covered by his excellent paper and the writer will only attempt to briefly state certain requirements in the selection of a design of locomotive which appear to be fundamentally necessary.

Weight limitations are all-important and come increasingly into considerations of design for modern power. Other things being equal, that engine which can develop the most power at the drawbar for the least weight on the rails and at the lowest cost is the one which must in the end hold the greatest favor.

What is required is not only an increase in power of the locomotive itself, but a reduction in maintenance and operating costs, having at the same time regard to the initial cost of the unit itself. With thousands of steam locomotives held idle and in good working order awaiting service at a time of peak business, it is apparent that any new construction offered will need to be sufficiently economical in operation to provide an adequate return to carry its own fixed charges for interest, insurance, taxes, and depreciation, in conjunction with an equal amount to currently retire the value of motive power displaced, otherwise no substantial progress in the way of new construction can reasonably be expected. Undoubtedly locomotive builders are approaching the various railroad administrations along this line. For this reason it is highly desirable that everything possible should be done to encourage every aim toward improvement in construction and design which holds any promise of value.

The principal considerations which have to be taken into account in the development of designs for locomotives are:

1 Maximum service availability
2 Maximum reliability
3 Minimum weight with maximum power, at the drawbar, rear of tender
4 Minimum maintenance expense
5 Minimum fuel and water consumption per unit of service rendered
6 Minimum initial cost consistent with items 1 to 5, inclusive.

The thermal efficiency of the modern locomotive is not high, and there is, for this reason, a large opportunity for the improvement of design and construction in this respect. Financial results do represent the controlling factor, and it is no easy matter to justify the elimination of many so-called obsolete locomotives which are not yet written off the books because of insufficient accumulated depreciation reserve. In the same way it may easily result that one locomotive will develop tractive power on more money (fixed charges and full expense considered) but less coal than another locomotive using more coal but having a lesser investment or fixed charge. What is most needed is a clear conception of what particular design is best suited to the particular service considered, in order to make certain that every advantage has been taken of progress in practice when the locomotive goes into service, and not start a unit in life with a handicap of obsolescence. The very fact that designs are being improved and radically changed from former practice has undoubtedly resulted in a sense of hesitation or caution on the part of purchasers, because of the uncertainty of what future progress holds in store. Sufficient progress has already been made to justify the displacement of almost any locomotive twelve or more years old, provided the service requirements are such as to keep the new unit utilized to a normal degree. Using one's best discretion, which is the superior engine? The problem involves two avenues of measurement. The question is still further confused by the problem of utilization, and one of the main steps toward financial improvement will, undoubtedly, be in the increase of this important value. When this is done, aside from the capacity factor, fuel expense will gain in rank as compared with investment expense.

The locomotive is essentially a power unit, but individual classes of locomotives vary over a wide range of capacity: the high-powered freight unit, as in the 2-8-2 type, or Mikado class, and 2-10-2 type, or Santa Fe class, being those which have been most usually considered for freight service, while the 4-8-4 type, or Hudson class, and 4-8-4 type, or Northern class, are now largely employed for conveying passenger trains.

When high-pressure steam is contemplated and, viewing ultimates, in so far as present outlook permits, we need to realize the existence of a possible strong competitor in the form of the Diesel engine, because the strength of the latter lies in its high thermal efficiency. The steam engine in order to hold its place must achieve economical improvement to a point at which it is in open and reasonable equality with the internal-combustion locomotive. It seems that this equality is promised by high-pressure conditions. When considering comparative performances as a test of success it is necessary to give strict thought to the varying grades of fuel employed in order to arrive at absolute and relative thermal efficiencies. The investment-cost factor may be definitely in favor of the steam locomotive, even with the additions due to the more expensive apparatus for high pressure, and, inasmuch as this feature has a large bearing on operating costs, it should provide an element to be considered when choice of systems is involved.

Reliability of operation is a vital requirement in railroad service, because it involves not only the feature of giving satisfactory service to the public but also influences, to a major degree, the all-important problem, namely, the availability factor of the locomotive as an earning unit. Existing steam locomotives have proved themselves successful in this respect, regardless of maintenance expense to attain this end, and even though there are bound to be some initial difficulties in the application of higher pressures and temperatures, there really should be no ultimate handicap on this account. The feature of properly selecting materials represents the main responsibility in achievement, because high pressures and superheats, through stress action, and the weakening influence of temperature increase the severity of the conditions which the materials have to withstand. The reduced strength of metals at high temperatures is, however, the primary and most definite effect to be considered. The question of materials does decide temperature values, and the same information guides to a very great extent the point of

[3] Assistant to President, N. Y. Air Brake Co., E. Works, Watertown, N. Y. Mem. A.S.M.E.

view with respect to pressure limitations. As operating pressures increase, the necessity for employing steam expansively in the cylinders is made very important and the feedwater problem more serious. The pretreatment of feedwater to remove the hard scale-forming bases by methods that do not produce harmful gases in the steam, is a chemical problem worthy of the most serious attention, while deaeration of the condensate to remove oxygen and other gases that may aid corrosion is really a feature of purely mechanical procedure. With high steam pressures and the possibility of safety valves blowing off, the noise is a real nuisance; and then, again, the feature of having the safety valve close tightly against increased pressures needs due consideration.

When all is said and done, our task is that of producing power, in a practicable way, at the lowest overall cost. This involves not only the conservation of weight and fuel but of capital as well, and the latter is made up of two factors, namely: (1) the price paid for the locomotive, and (2) its probable life.

Charles J. Toth.[4] In the endeavor to develop the steam locomotive to the highest possible state of efficiency, it is fair to assume that it is entirely out of the question to continue with the early tradition. We are simply adding new devices and equipment to a conventional-type mechanical structure which, basically, does not differ from the designs laid down half a century ago.

### Improvement in Power Plants

We are rather faced to attack this important problem on the basis of a general redesign of our conventional-type locomotive, and to this end we must, most logically, follow more closely modern power-plant practice. It is only and exclusively in this field where we can find realized all the structural refinements and, above all, all the perfectly service-tested design features the incorporation of which will be indispensable to build a highly efficient steam locomotive.

In the trend toward adapting to locomotive practice all the approved heat-saving appliances of our modern central stations, of course, due allowance has to be made to all the special problems which arise in locomotive practice owing to conditions peculiar to that service. In the course of this delicate work we shall find that certain difficulties may arise, particularly due to the fact that weight and space are at more of a premium in locomotive design than they are in any other steam plant; but, in the light of present knowledge and experience, the eventual difficulties are by no means insurmountable and require only care in design.

Taking now into thorough account the present power-plant situation and reviewing every detail of the research and development work already done, we see that the very rapid progress of power-plant development seems to have replaced a stage where the station efficiencies were getting close to the ultimate possibilities of the steam cycle generally employed.

With regard to the conventional type of stationary plant, it is now thought that the use of a steam pressure of 1250 lb. per sq. in. represents the ultimate practical limit, and that there can be hardly a practical gain in going to steam pressures in excess of that figure, at least *as long as we resort to the conventional method of steam generation* with all its inherent difficulties due to priming and boiling. In fact, it can be stated with safety that the theoretical gain that can be achieved above this pressure is so small that the cost of getting it is likely to outweigh the small percentage of improvement that can be accomplished.

[4] Montevideo, Uruguay, S. A.

### Super-Pressure Generating System

Fortunately enough, just at the time when the possibilities for a further improved power-plant practice seemed to be beyond the scope of the engineers' ability to solve, there appeared new schemes in the form of the perfection of other than the conventional steam-generating cycles (Atmos, Loeffler, Benson, etc.), and we are now permitted to look with more optimism into the future.

All the pioneer work undertaken in connection with these new schemes and carried out with the purpose of showing that the results which can be expected are reasonably satisfactory, is very well advanced, and all the original claims seem to be completely substantiated. The test results obtained with different experimental plants leave little doubt about the fact that substantially lowered guaranteed fuel consumptions may be obtained and that, finally, we may foresee a theoretical plant efficiency equivalent to a fuel consumption of 7300 B.t.u. per hp-hr. output.

### Super-Pressures for Locomotives

What particularly distinguishes our interest in the subject of the new steam-generating schemes is the fact that, aside from the very low fuel consumption, the new-type plants are of a reduced size and weight, and perhaps owing to their relative simplicity considerably cheaper to build and to maintain than is the case with a conventional-type plant of equal capacity. Hence, in spite of the existing limitations in locomotive design, due to crowded clearance and restrictive weights, it will be easier to adapt to locomotive practice the new super-pressure plants than was the case with the heavier and bulkier conventional-type high-pressure plants.

To appreciate properly the value of the new locomotives, we must, most logically, introduce more up-to-date standards of comparison and scrap certain misconceptions which form the basis from which much erroneous reasoning emanates. Neither must we be hampered by men whose visions cannot extend beyond next year's dividends and who cannot see the future which lies before railway locomotion.

The proposed locomotives will be much costlier to build than any of our present-day locomotives, but if the deciding utility factor, the ton-mile-hour capacity, is examined, the considerably increased earning capacity of the new locomotive becomes most evident, and this item alone justifies part of the 200 to 220 per cent higher cost of construction. If, then, we consider the intensive continuous utilization of the modern power plant and imagine keeping in operation the new locomotives during several days continuously, instead of confining them to six to nine hours' work per day, we can see a single new locomotive replacing two or even three of the conventional-type engines and so fully justifying the increased cost of construction.

Such being the case, all the other items, such as the considerable savings on account of fuel economy (an average of 11,000 B.t.u. per horsepower as against the present figure of 31,000), the lessened boiler troubles owing to the use of pure condensate as feedwater, and, last but by no means least, the lowering of track-maintenance costs due to the greatly improved roadability, will represent additional assets in favor of the new locomotives.

### A Tentative Design of Super-Pressure Locomotive

A tentative design of a super-pressure locomotive, shown in Fig. 22, has been developed on the basis of the following considerations:

As the steam turbine is more readily adaptable to the most severe steam conditions and seems to be, more than any existing reciprocating engine, reliable under extreme working pres-

sures and temperatures, the new design has been developed as a steam-turbine locomotive.

The steam, generated at critical pressure, is throttled to more moderate conditions and its temperature subsequently increased to a proper relative figure. The first expansion is arranged to take place within the stationary nozzles of the primary turbines so as to supply steam of moderate temperature to the impulse blading. In this way the highest temperatures will remain confined to the piping and high-pressure nozzles, these latter conveniently arranged within special chambers mounted separately from the turbine cylinder, except for points of attachments and guides.

will be composed of two power trucks, one carrying the boiler plant, high-pressure turbines, and the principal control organs, and the other carrying the low-pressure turbine, the complete condensing equipment, and the fuel and water tanks.

Owing to the largely fluctuating load characteristics which prevail in railroad operating practice, it is proposed to use oil fuel in order to permit the necessary very flexible fire control. With certain refinement and perfections in the design of the corresponding equipment, it will be possible later to resort to powdered-coal-firing systems.

To provide for the perfect self-contained operation of the plant as a whole, the super-pressure plant will be in direct combination

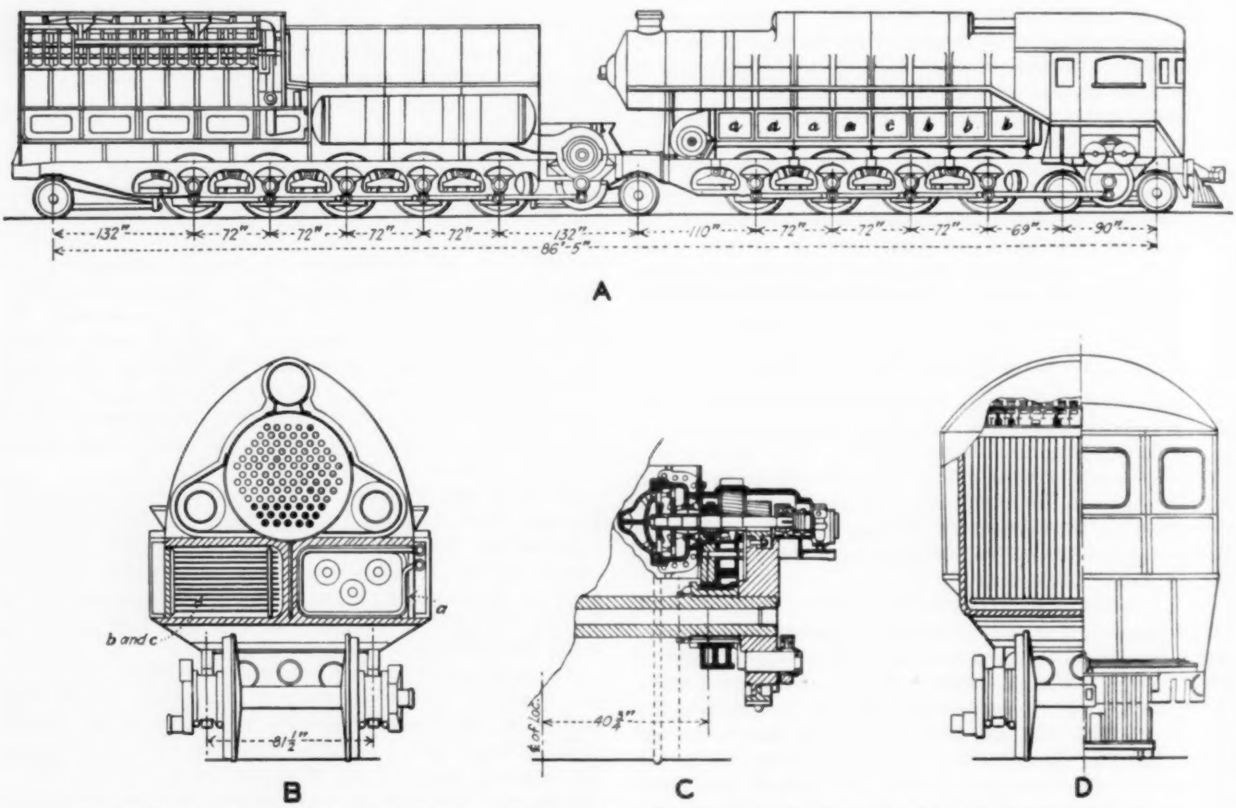


Fig. 22 Elevation and Sectional Views of Proposed Critical-Pressure Condensing Steam-Turbine Locomotive
(*A*—side elevation; *B*—sectional view showing heating tubes; *C*—sectional view of primary turbine; *D*—sectional view showing interstage superheater.)

Compound turbines have been adopted for, among others, the following reasons:

1 The cross-compound arrangement of turbines machinery is less likely to be completely incapacitated and represents, therefore, a greater degree of potential reliability, so essential in railroad work.

2 Further assurance of the greater overall potential reliability lies in the arrangement for the independent operation of any of the prime-mover elements involved.

3 Within a subdivided machinery it is easier to localize any operating trouble.

4 The reheating cycle, so important in any thermal process, becomes more advantageous with subdivided machinery.

5 The compound-turbine arrangement is of utmost importance from the point of view of permitting a greater percentage of the total locomotive weight being utilized as adhesive weight, and, consequently, the attainment of maximum capacity on the adhesive range with a given maximum weight of the locomotive.

In consideration of the foregoing the proposed locomotive with a barrel-type boiler (the cheapest design and permitting a large amount of water reserve with a relatively light-weight boiler structure) designed to carry a steam pressure up to 325 lb. per sq. in.

The critical-pressure generator will consist of bundles of $^{13}/_{16}$-in. inside- and $1^{11}/_{64}$-in. outside-diameter tubes, subdivided into 16 groups with 8 groups located on each side of the locomotive.

In view of the recognized fact that the valuable heat of the furnace is the radiant heat and that it is not productive of best results to reflect it too much back and forth between costly and easily destroyed walls of firebrick, it is proposed to place the tubes constituting the primary evaporative section in the form of a "close screen" near the furnace walls. So the tubes of these sections *a* receive the direct radiating heat of the flame, and at the same time the furnace walls are prevented from heating up to the fusing temperature.

The highly preheated feedwater extracted from the barrel boiler will be delivered by means of a plunger pump, at critical

pressure, to the tube sections *a*. The water enters these tubes at a pressure of 3250 lb. per sq. in. in the front portions of the successive coils, so that operation proceeds on the counter-current principle.

After acquiring a small amount of superheat within the primary coils, thus providing a margin of safety to insure that the critical point is passed before the fluid leaves the coils, the steam will pass through the tube bundles *b* where the evaporation will be completed. The temperature of the steam at the entrance will be about 730 deg. fahr., and at the exit about 790 deg.

The pressure then will be throttled to 1750 lb. and the temperature brought back near the conditions of saturation. Next it will pass through the tubes of sections *c* where its temperature will be again raised, and according to the actual load conditions may reach up to 800 deg. fahr.

The highly superheated steam will expend a portion of its energy within two two-stage primary turbines (one of them shown at *C* in Fig. 1) and will exhaust at about 300 lb. pressure. It is proposed to operate the two primary turbines in series as regards steam flow and in parallel mechanically. Each turbine is to be overhung on its shaft, thus avoiding the necessity of employing high-pressure packings.

The exhaust steam, at about 300 lb. pressure, will be led first through the interstage superheater located at the front portion of the boiler plant (Fig. 22, *D*) in the direct path of the combustion gases where they leave the critical-pressure boiler and, after having been reversed in their direction of flow, will enter the barrel boiler. Here it will be reheated to about 680 to 700 deg. fahr. and then carried to the low-pressure turbine located on the front portion of the tender truck.

A pressure-regulating device incorporated in one of the pressure stages of the main turbine will control the speed of the critical-pressure feed pump, and thus the output of the critical-pressure steam generator. A similar arrangement is being made for the automatic regulation of the air supply and the output of the fuel pump, with the consequent variation in the amount of fuel fed into the main burners. Eventually, with diminishing loads, some of the six main burners may be cut out of operation.

The critical-pressure boiler is being designed to produce up to 12,500 lb. of steam per hour. The tubes of each evaporative section *a* will have 109 sq. ft. of heating surface, hence a total of 872 sq. ft. within the eight sections (four on each side of the locomotive). Within sections *b* and *c* the tubes will be placed horizontally (Fig. 22, *B*), each section's tubes having a heating surface of 308 sq. ft. Thus the distribution of the total heating surface to the different tube sections will be as follows: 8 sections *a*, 872 sq. ft.; 6 sections *b*, 1848 sq. ft.; 2 sections *c*, 616 sq. ft., making a total of 3336 sq. ft.

All connections to the high-pressure tube sections *a*, *b*, and *c* will be located outside the furnace space, within special compartments on both sides of the boiler, and easily accessible. The tube sections of the super-pressure plant are designed for easy and individual removal.

The low-pressure section of the steam-generating plant will consist essentially of a barrel boiler with 100 per cent water and filled completely with fire tubes providing for a total heating surface of 2240 sq. ft. A steam drum is to be located on top of the barrel boiler and extending nearly its full length. The barrel boiler will have two lateral cylindrical portions, each containing a large-diameter fire flue and an auxiliary burner within each flue. In another design the two large-diameter fire flues have been incorporated into the interior of the barrel boiler. The object of this arrangement is to provide means for the independent generation of 325-lb. steam in the event that the super-pressure generator be out of commission.

It is intended that the auxiliary burners shall enter into operation only for the generation of the steam necessary to start the operation of the super-pressure boiler. But, of course, this arrangement provides also for the possible operation of the locomotive as a 325-lb. pressure-turbine locomotive, if required through the unlikely event of a complete failure of the critical-pressure plant. In the latter event the 325-lb. steam will be superheated within the coils, which, in ordinary operation, will serve as interstage reheaters of the working steam. It may be added that in this form of operating the locomotive, the tubing of the super-pressure plant will not come into direct contact with the combustion gases leaving the auxiliary burners.

The interstage superheater (left-hand portion of Fig. 22, *D*) will be built up of $^{13}/_{16}$-in.-diameter tubes placed vertically and expanded into cylindrical headers. Appropriate extensions on the headers will contain all the necessary valves for the control of the following alternate methods of operation:

1 Give free passage for the working steam between the primary and low-pressure turbines without the addition of steam from the barrel boiler.

2 The same function as under 1 with the difference that steam is added from the barrel boiler to the interstage steam in varying amounts according to the momentary load conditions.

3 Cut off the communication between the primary and low-pressure turbines and admit steam direct from the barrel boiler for the operation of the low-pressure ahead turbine.

4 As under 3 with the difference that the steam admitted is for the operation of the low-pressure reversing turbine.

No high-pressure reversing turbines are specified, the idea being to avoid the necessary arrangement of duplicate high-pressure turbines or else the arrangement of reversing gear.

To lessen the necessity for the operation of the auxiliary burners, the following arrangement has been adopted:

A bypass in the 1750-lb. steam piping between the primary turbines and the steam generator will be provided. During the periods of stopping the primary turbines, the critical-pressure plant will be kept operating, at a lower or the lowest possible rate of output, and the highly superheated steam thus generated admitted to a series of heating elements located within the lower portion of the barrel boiler. Within these elements the live steam will first be desuperheated and then expanded by means of adequate nozzles down to the pressure existing within the barrel boiler, and its heat content completely exchanged with the water content of the barrel boiler.

All prime movers are designed for a maximum speed of 8900 r.p.m. and are provided with exactly identical double-reduction gearing of a ratio of 1:24. The design of the primary turbines has already been indicated and is shown in Fig. 22, *C*. The low-pressure turbine consists of a two-stage impulse wheel and nine rows of reaction blading for the ahead turbine. On the same shaft is provided a two-stage impulse wheel and four rows of reaction blading for the reversing turbine.

Of course, with a view of cutting costs it would be perfectly feasible to adopt the complete low-pressure turbine, condensing equipment and auxiliaries of one of the perfectly service-tested turbine locomotives and dispose all this equipment on a tender truck. (Either the Zoelly of the Ljungström locomotive equipment is available.) Such a truck would then be combined with one carrying the steam generator and the primary turbines, etc. Since little experimentation is necessary with the above-mentioned low-pressure turbine equipment, the expenses would be confined to experiments with the super-pressure machinery. Thus the proceedings which are being adopted with good results in experimental super-pressure central stations would be followed.

The framing of both trucks, located outside the wheels, is cast in one piece with all necessary transverse members and

bedplates. The manner of coupling the two trucks together through the use of a pivot pin and a pony truck is indicated in Fig. 22, *A*.

It is not considered necessary to give at present a more detailed description of the condensing equipment, as this is supposed to be well known from data on the many existing turbine locomotives. However, the writer would state that he is inclined to favor the application of a surface-condenser system, as this type of equipment is much less delicate than the evaporating-type condenser. The method of recooling the circulating water is the well-known sprinkler system.

The general arrangement of the auxiliaries inherent to the condensing equipment also need not be described, as this is the same as employed on existing turbine locomotives. However, attention may be directed to the application of a duplicate draft arrangement. An induced-draft fan, turbine-driven, is located at the left end of the smokebox, and a forced-draft fan is located beneath the smokebox. The turbine drive of the latter is in direct combination with the drive of the fuel pump so that the output of the fuel is automatically adjusted to the amount of of preheated combustion air delivered to the burner castings. The forced-draft fan draws the combustion air through the preheater which is located within the smokebox and has a total heating surface of 1850 sq. ft.

No feedwater heater is provided, the waste heat in the flue gases being restored to the system by means of the air preheater.

The pure condensate available for the boiler feed is preheated by means of the steam exhausting from the engine driving the critical-pressure plunger pump and from the turbines driving the draft fans.

The critical-pressure plunger pump is located within a special compartment of the cab, where it is as convenient as any of the principal steam control valves.

As regards the location of the cab at the front end of the locomotive, the writer believes little discussion as to the advantages is necessary. It appears illogical to impose ever greater responsibility upon the engineman and in addition confine him behind a 30-ft. to 50-ft. boiler structure of excessive cross-sectional area where he remains bereft of the clear vision so essential from the standpoint of safety in train operation.

## Conclusions

Railway authorities who are conscientiously aware of their great responsibilities should take into consideration all the ways and means available to bring the steam locomotive to the highest possible state of efficiency. If they come to the conclusion that the adaptation of some service-tested method will really bring about important advantages in operating efficiency and economy there is no necessity for insisting on going step by step through all the possible intermediate and less efficient development stages. We are perfectly justified in making an important unconventional jump forward, the more so because it brings us nearer to the desired goal. In this the writer believes all interested parties will concur.

From the standpoint of an impartial judgment it may be stated with safety that there is nothing freakish about the realization of a critical-pressure locomotive, because actual practice has taught us how to control with reasonably satisfactory results steam of extreme pressure and temperature conditions. Moreover, it is well to keep in mind the fact that for a long time hydraulic and pneumatic plants have been in successful operation at pressures of several thousands of pounds per square inch.

In our internal-combustion engines, in addition to high pressures we also encounter temperatures far in excess of those contemplated within the proposed super-pressure locomotive.

Why then should we have doubts about the possible perfect control of high pressures and temperatures within the proposed new steam locomotives?

The means for the proper construction and control of the new machinery are at hand—it remains then to understand, or rather be willing, to utilize them properly. Realizing this, we can be confident that development will not stop with the present state of the art of producing power for rail transportation. However, the future is entirely dependent upon the question of finding some progressively minded railroad operator who neither lacks the imagination in gaging the immediate and future possibilities nor the courage to decide in favor of the application of new schemes to actual installations.

TABLE OF DIMENSIONS AND WEIGHTS

| | | |
|---|---|---|
| Type of locomotive | | 4-8-2-10-2; (2-D-1-E-1) |
| Speed of turbines at the maximum locomotive speed of 63 m.p.h. | | 8900 r.p.m. |
| Diameter of driving wheels | | 57 in. |
| Weights in working order | Adhesive weight | 554,600 lb. |
| | Front truck | 69,200 lb. |
| | Central truck | 58,000 lb. |
| | Trailing truck | 42,800 lb. |
| Total weight of locomotive | | 724,600 lb. |
| Total wheelbase | | 86 ft. 5 in. |
| Maximum rigid wheelbase | | 18 ft. |
| Capacity of the critical-pressure generator | | 12,500 lb. per hr. |
| Capacity of cooling-water tanks | | 90,000 lb. |
| Capacity of feedwater tanks | | 24,000 lb. |
| Capacity of fuel-oil tanks | | 24,000 lb. |
| Combined output of the critical- and low-pressure turbines | | 3,500 hp. |
| Tractive effort | | 168,000 lb. |

## Author's Closure

The paper as presented is intended to be complete in itself. For a full understanding of the author's viewpoint, however, it is necessary to consider it in conjunction with the articles referred to therein, namely, those published in the September and October, 1927, issues of the *Railway Mechanical Engineer*. In those articles many of the questions brought up by Mr. Fry and Mr. Sillcox are dealt with.

Mr. Fry's estimate of the furnace volume available is, the author believes, about correct. It is the same as was given in the latter's article in the September issue of the *Railway Mechanical Engineer*. The efficiency, 85 per cent, however, was taken for an average loading which was assumed in the article as between one-half and three-fourths maximum. Taking 4000 hp. as the average load would therefore give a maximum load of about 6400 hp. at the same rate or, say, 6000 hp. at a reduced efficiency. This is a higher power than the author assumed for a furnace volume of 800 cu. ft. Considering all the conditions assumed, it is his belief that the efficiency of 85 per cent is conservative. It should be remembered that this efficiency is not for the boiler alone but includes the performance of the economizer, superheater, and air preheater. It also includes fine pulverization, turbulent burners, and a furnace equipped with suitable slag screens.

Mr. Sillcox in his discussion brings up some of the defects of the present locomotive, such as high maintenance, relatively low service availability, large weight relative to the tractive force and power capacity, and low efficiency. It is evident that any design departing from standard practice must be an improvement in these respects to be of value. The author feels that in all the ways mentioned a high-pressure condensing locomotive can be produced that will be a material improvement over present practice. The first cost of a locomotive to accomplish this should not materially increase the fixed charges. It is evident, however, that for the design advanced, pulverizing and make-up water evaporating plants would be required and new maintenance equipment would be needed. To make this worth while the increase in economy must be large.

At the present time the steam-driven locomotive, even with its low efficiency, has not a very much higher fuel charge than would

be required for a Diesel drive at the present cost of oil. This would hold for average conditions in this country. In addition a large use of fuel oil could be depended upon to jump the price considerably. It appears to the author that for general use it would be more promising to attempt to develop the steam drive to an efficient basis. Below he gives a comparison of power costs for Diesel and steam drives.

| Locomotive | Efficiency, per cent | Power, B.t.u. for 1 cent |
|---|---|---|
| Present standard | 7 | 7,000 |
| High-pressure condensing | 20 | 18,000 |
| Present Diesel-engine drive | 25 | 7,280 |
| Improved Diesel-engine drives (est.) | 33 | 9,600 |

These figures are based on coal at $2.66 per ton with an allowance of 10 per cent additional for pulverizing in the case of high-pressure condensing steam locomotives. Oil is considered at approximately 0.6 cent per lb. The price of the coal used is the average cost to the railroads during one of the recent years. The price of fuel oil is the approximate present price delivered at a water terminal. Both will vary, depending on location. At the present time it appears to be feasible to develop high-pressure condensing steam locomotives with a thermal efficiency equal to that set down. Manufacturers in Europe, it is understood, will now guarantee certain types of standard-pressure turbine condensing locomotives to have 17 per cent thermal efficiency.

# Vibration of Bridges

By S. TIMOSHENKO,[1] ANN ARBOR, MICH.

*It is well known that a rolling load produces in a bridge or in a girder a greater deflection and hence greater stresses than the same load acting statically. This "impact effect" of live loads on bridges is of great practical importance. In this paper the following kinds of impact are analyzed:*

*1 "Live-load effect" of a smoothly running load*
*2 "Impact effect of balance weights" of locomotive driving wheels*
*3 "Impact effect due to irregularities." These irregularities include irregularities in the track and also flat spots on wheels.*

*It is shown that the "live-load effect" of a smoothly running load is small and can be always neglected. The "impact effect of balance-weights" may be of considerable importance, especially under conditions of resonance, and is most severe on bridges of the shortest span which will allow resonance conditions to occur. For the assumptions made in this paper the minimum length of the span to allow such resonance will be about 100 ft.*

*The "impact effect due to irregularities" of track may attain considerable magnitude in the case of short girders and rail bearers. By removing such discontinuities in the track as rail joints a considerable decrease in impact stresses produced in bridge parts directly subjected to the dynamical effect of moving wheels can usually be accomplished.*

It is well known that a rolling load produces in a bridge or in a girder a greater deflection and greater stresses than the same load acting statically. Such an "impact effect" of live loads on bridges is of great practical importance, and many engineers have worked on the solution of this problem.[2] There are various causes for these impact effects, and in the following

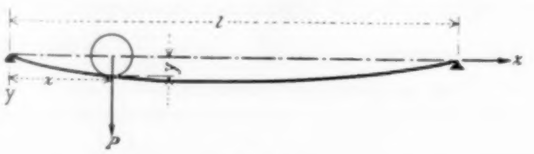


Fig. 1

such impact effects as (1) "live-load effect" of a smoothly running load, (2) "impact effect of the balance weights" of the locomotive driving wheels and (3) "impact effect due to irregularities," which includes irregularities in the track and flat spots on wheels, are discussed.

### Live-Load Effect of a Smoothly Running Mass

In discussing this problem two extreme cases are considered: (1) the mass of the moving load large in comparison with the mass of the bridge, and (2) the mass of the moving load small in comparison with the mass of the bridge. In the first case the mass of the bridge, can be neglected. Then the deflection of the bridge under the load at any position of this load will be proportional to the pressure $R$ which the rolling load $P$ produces on the beam (Fig. 1), and can be calculated from the known equation of statical deflection

$$y = \frac{Rx^2(l-x)^2}{3lEI} \qquad [1]$$

in which $EI$ = flexural rigidity of the beam. Other notations are given in Fig. 1. In order to obtain the pressure $R$ the inertia force $-\frac{P}{g}\frac{d^2y}{dt^2}$ should be added to the rolling load $P$. Assuming that the load is moving along the beam with a constant velocity $v$, we obtain

$$\frac{dy}{dt} = \frac{dy}{dx}\frac{dx}{dt} = v\frac{dy}{dx} \qquad \frac{d^2y}{dt^2} = v^2\frac{d^2y}{dx^2}$$

The inertia force becomes $-\frac{P}{g}\frac{d^2y}{dt^2} = -\frac{P}{g}v^2\frac{d^2y}{dx^2}$, and the pressure on the beam will be

$$R = P\left(1 - \frac{v^2}{g}\frac{d^2y}{dx^2}\right) \qquad [2]$$

Substituting in Equation [1] we obtain

$$y = P\left(1 - \frac{v^2}{g}\frac{d^2y}{dx^2}\right)\frac{x^2(l-x)^2}{3lEI} \qquad [3]$$

This equation determines the trajectory of the point of contact of the rolling load with the beam.[3] A good approximation for the solution of Equation [3] will be obtained by assuming in calculating the inertia force that the deflections are the same as at zero speed ($v = 0$). The value

$$\frac{Px^2(l-x)^2}{3lEI}$$

may therefore be substituted for $y$ in the right side of this equation. Then by simple calculations it can be shown that $y$ becomes a maximum when the load is at the middle of the span, and the maximum pressure will be

$$R_{\max.} = P\left(1 + \frac{v^2}{g}\frac{Pl}{3EI}\right) \qquad [4]$$

The maximum deflection in the center of the beam increases at the same rate as the pressure on it, so that

$$\delta_d = \delta_{st}\left(1 + \frac{v^2}{g}\frac{Pl}{3EI}\right) \qquad [5]$$

This approximate solution, as compared with the result of an exact solution of Equation [3],[4] is accurate enough for practical applications. The additional term in the brackets is usually very small, and it can be concluded that the "live-load effect" in the case of small girders has no practical importance.

In the second case, when the mass of the load is small in comparison with the mass of the bridge, the moving load can be replaced with sufficient accuracy by a moving force. The problem then consists of determining the vibrations of the bridge produced by a vertical force $P$ moving along the bridge with a constant velocity $v$. The complete solution of this problem is

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[2] The history of the subject is extensively discussed in the famous book by Clebsch. Translated by S. Venant (Paris, 1883). See Note of § 61, p. 597.

Contributed by the Railroad Division and presented at the Annual Meeting, New York, December 5 to 8, 1927, of The American Society of Mechanical Engineers.

[3] This equation was established by Willis, Appendix to the Report of the Commissioners to inquire into the Application of Iron to Railway Structures (1849), London.

[4] The exact solution of the Equation [3] was obtained by G. G. Stokes. See Math. and Phys. Papers, vol. 2, p. 179.

given in the Appendix. It is there shown—see Equation [43]—that the amplitude of vibration depends on the value of the ratio:

$$\alpha = \frac{T}{2T_1} \qquad [6]$$

where $T$ = natural period of vibration of the bridge, and
$T_1$ = time it takes the force to pass over the bridge.

Taking the most unfavorable assumption regarding the superposition of statical deflection and deflection due to vibration, and neglecting damping, the following equation for maximum deflection produced by a moving force $P$ will be obtained (see Appendix).

$$\delta_d = \frac{\delta_{st}}{1 - \alpha} \qquad [7]$$

in which $\delta_d$ = maximum dynamical deflection, and
$\delta_{st}$ = the deflection produced by the same force when applied at the middle.

The value of the quantity $\alpha$ is usually small; therefore the dynamical effect of a smoothly running load is usually negligible. Let us take as an example three bridges of different spans $l$ = 60 ft., $l$ = 120 ft., and $l$ = 360 ft. The approximate values of the periods $T$ of natural vibrations are given in the second line of the table below. In the third line of the same table the time $T_1$ for the load to pass over the bridge ($v$ = 120 ft. per sec.) is given, while in the fourth line we have the calculated values of the ratio $\alpha = T/2T_1$. The largest effect of running load is thus obtained for the smallest span and from the table it can be concluded that for this span and with a very high velocity the increase in deflection due to the live-load effect is about 12 per cent, and this is still diminished with decrease in velocity and with increase in length of span.

| | | | | |
|---|---|---|---|---|
| $l$ | = | 60 ft. | 120 ft. | 360 ft. |
| $T$ | = | $^1/_9$ | $^1/_5$ | $^1/_2$ |
| $T_1$ | = | $^1/_2$ | 1 | 3 |
| $\alpha = \frac{T}{2T_1}$ | = | $^1/_9$ | $^1/_{10}$ | $^1/_{12}$ |

If several moving loads are acting on the bridge the oscillations associated with these should be superimposed. Only in the exceptional case of synchronized vibrations will the resultant live-load effect on the system be equal to the sum of the effects of the separate loads and the increase in deflection due to this effect be in the same proportion as for a single load. From these examples it can be concluded that the live-load effect of a smooth-running load is not an important factor, and even in the most unfavorable cases it will hardly exceed 10 per cent. Much more serious effects may be produced, as we shall see now, by the pulsating forces produced by the rotating balance weights of steam locomotives.

### Impact Effect of Balance Weights

The most unfavorable condition occurs in the case of resonance when the number of revolutions per second of the driving wheels is equal to the natural frequency of vibration of the bridge. For a short-span bridge the natural frequency is usually so high that synchronism of pulsating load and natural vibration is impossible at any practical velocity. By taking, for instance, six revolutions per second of the driving wheels as the highest limit and taking the frequencies of natural vibration from the table above, it can be concluded that the resonance condition is hardly possible for spans less than 100 ft. in length. For longer spans resonance conditions should be taken into consideration, and the impact effect should be calculated on this assumption.

The complete discussion of forced vibrations produced by balance weights is given in the Appendix; here the application of the final equation (see p. 8) only will be shown.

Let $P_1$ = maximum resultant pressure on the rail due to the counterweights when the driving wheels are revolving once per second

$\frac{P_1}{T^2}$ = resultant pressure on the rail when the number of revolutions of the wheel per second is equal to natural frequency $1/T$ of the bridge

$n$ = total number of revolutions of the driving wheels during passage along the bridge.

Then from Equation [45], given in the Appendix, we obtain the following additional deflection due to the impact effect of driving wheels:

$$\delta_{max.} = \frac{2n}{T^2}\frac{2P_1l^3}{EI\pi^4} \qquad [8]$$

It is seen that in calculating the impact effect due to balance weights such quantities as (1) the statical deflection $\frac{2P_1l^3}{EI\pi^4}$ produced by the force $P_1$, (2) the period $T$ of the natural vibration of the bridge, and (3) the number of revolutions $n$ should be taken into consideration. All these quantities are usually disregarded in impact formulas as applied in bridge design.

In order to obtain an idea of the amount of this impact effect let us apply Equation [8] to a numerical example[5] of a locomotive crossing a bridge of 120 ft. span. Assuming that the locomotive load is equivalent to a uniform load of 14,700 lb. per linear foot distributed over a length of 15 ft., and that the train load following and preceding the locomotive is equivalent to a uniformly distributed load of 5500 lb. per linear foot, the maximum central deflection of each girder is $\frac{2l^3}{EI\pi^4}(275{,}000)$, approximately. The same deflection when the locomotive approaches the support and the train completely covers the bridge is $\frac{2l^3}{EI\pi^4}(206{,}000)$, approximately. Taking the number of revolutions $n$ = 8 (the diameter of the wheels being equal to 4 ft. 9 in.) and the maximum pulsating pressure on each girder at the resonance condition equal to $\frac{P_1}{T^2}$ = 18,750 lb., the additional deflection, calculated from Equation [8] will amount to

$$\frac{2l^3}{EI\pi^4}\ (300{,}000)$$

Adding this to the statical deflection, calculated above for the case of the locomotive approaching the end of the bridge, we obtain the complete deflection at the center equal to $\frac{2l^3}{EI\pi^4}$ (506,000). Comparing this with the maximum statical central deflection $\frac{2l^3}{EI\pi^4}$ (275,000), given above, it can be concluded that the increase in deflection due to impact is, in this case, about 84 per cent. Assuming the number of revolutions $n$ equal to 6 (the diameter of driving wheels equal to $6^1/_2$ ft.) and assuming again a condition of resonance, we obtain for the same numerical example an increase in deflection equal to 56 per cent.

In the case of bridges of shorter spans, where the natural frequency of vibration is considerably higher than the number of revolutions per second of the driving wheels, a satisfactory

[5] The loading conditions following are taken the same as in the paper by C. E. Inglis. See Proc. Inst. of Civil Engineers, vol. 218 (1924), London.

approximation can be obtained by using the general solution, Equation [44], given in the Appendix. By taking only the first term of this solution and assuming the most unfavorable condition, we arrive at Equation [46], which must be used in this case.

Consider, for instance, a 60-ft-span bridge, and assume the same kind of loading as in the previous example, then the maximum statical deflection is $\frac{2l^3}{EI\pi^4}$ (173,000), approximately. If the driving wheels have a circumference of 20 ft. and make 6 revolutions per second, the maximum downward force on the girder will be $18{,}750\left(\frac{6}{5}\right)^2 = 27{,}000$ lb. Assuming the natural frequency of the bridge equal to 9, we obtain, from Equation [46],

$$\delta = \frac{2l^3}{EI\pi^4}\,(27{,}000 \times 2.57) = \frac{2l^3}{EI\pi^4}\,(69{,}400)$$

hence

$$\frac{\text{dynamical deflection}}{\text{statical deflection}} = \frac{173 + 69.4}{173} = 1.40$$

The impact effect of the balancing weights in this case amounts to 40 per cent.

In general, it will be seen from the theory developed that the most severe impact effects will be obtained in the shortest spans for which a resonance condition may occur (about 100-ft. spans for the assumption made above), because in this case the resonance occurs when the pulsating disturbing force has its greatest magnitude. With increase in the span the critical speed decreases, and also the magnitude of the pulsating load; consequently the impact effect decreases.

For very large spans, when the frequency of the fundamental type of vibration is low, synchronism of the pulsating force with the second mode of vibration having a node at the middle of the span becomes theoretically possible. Therefore, due to this cause an increase in impact effect may occur at a velocity about four times as great as the first critical speed.

It should be noted that all our calculations have been based on the assumption of a pulsating force moving along the bridge. Under actual conditions we have rolling *masses*, which will cause a variation in the natural frequency of the bridge in accordance with the varying position of the loads. This variability of the natural frequency, which is especially pronounced in short spans, is very beneficial because the pulsating load will no longer be in resonance all the time during passage over the bridge, and its cumulative effect will not be as pronounced as is given by the above theory. From experiments made by the Indian Railway Bridge Committee[6] it is apparent that, on the average, the maximum deflection occurs when the engine has traversed about two-thirds of the span, and that the maximum impact effect amounts to only about one-third of that given by Equation [8]. It should be noted also that the impact effect is proportional to the force $P_1$, and therefore depends on the type of engine and on the manner of balancing. While in a badly balanced two-cylinder engine the force $P_1$ may amount to more than 1000 lb.,[7] in electric locomotives perfect balancing can be obtained without introducing a fluctuating rail pressure. This absence of impact effect may compensate for the increase of axial weight in modern heavy electric locomotives.

In the case of short girders and rail bearers whose natural frequencies are very high, the effect of counterweights on the deflection and stresses can be calculated with sufficient accuracy by neglecting vibrations and using the statical formula in which the centrifugal forces of counterweights should be added to the statical rail pressures. The effect of these centrifugal forces may be especially pronounced in the case of short spans when only a small number of wheels can be on the girder simultaneously.

[6] See Bridge Sub-Committee Reports, 1925, Calcutta: Government of India Central Publication Branch, Technical Paper No. 247 (1926).

[7] Some data on the values of $P_1$ for various types of engines are given in the Bridge Sub-Committee Report, mentioned above.

### Impact Effects Due to Irregularities of Track and Flat Spots on Wheels

Irregularities such as rail joints, low spots on the rails, or flat spots on wheels, etc., may be responsible for considerable impact effect which may become especially pronounced in the case of short spans. If the low spots in the track or the flat spots on the wheels have the shape of a smooth curve, the same method as used in the analysis of track stress[8] can be applied here also. The following analysis for obtaining the maximum dynamical effect assumes a rigid track, the flexibility being neglected. Let the equation

$$y = \frac{\delta}{2}\left(1 - \cos\frac{2\pi x}{l}\right) \qquad [9]$$

represent the shape of a low spot on a rail, shown in Fig. 2. If

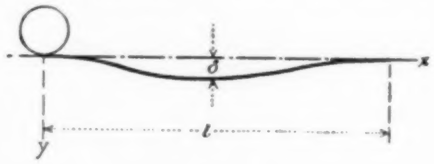


Fig. 2

a wheel of the mass $P/g$ is moving along this curve with a constant velocity $v$, the velocity of the load in the vertical direction will be

$$\frac{dy}{dt} = \frac{dy}{dx}\frac{dx}{dt} = v\frac{dy}{dx}$$

and the corresponding acceleration is

$$\frac{d^2y}{dt^2} = v^2\frac{d^2y}{dx^2}$$

Substituting [9] for $y$ we obtain

$$\frac{d^2y}{dt^2} = \frac{4\pi^2}{l^2}\frac{\delta v^2}{2}\cos\frac{2\pi x}{l}$$

The inertia force, which must be added to the statical load $P$ and which represents the dynamical effect in this case, will be

$$-\frac{P}{g}\frac{d^2y}{dt^2} = -\frac{P}{g}\frac{4\pi^2}{l^2}\frac{\delta v^2}{2}\cos\frac{2\pi x}{l}$$

The maximum value of the additional pressure on the rail due to this inertia force of the moving wheel will be obtained when $x = \frac{l}{2}$ and $\cos\frac{2\pi x}{l} = -1$. Then

$$\left(-\frac{P}{g}\frac{d^2y}{dt^2}\right)_{\text{max.}} = \frac{P}{g}\frac{4\pi^2}{l^2}\frac{\delta v^2}{2} \qquad [10]$$

It is seen that the additional pressure will be proportional to the unsprung mass of the wheel, to the square of the velocity of the train, and to the ratio $\delta/l^2$. This pressure may attain a considerable magnitude, and is therefore of practical importance in the

[8] See "Applied Elasticity," by S. Timoshenko and J. M. Lessells, p. 334.

case of short bridges and rail bearers. This additional dynamical effect produced by irregularities in the track and flats on the wheels justifies the high impact factor usually applied in the design of short bridges. By removing rail joints from the bridges and by using ballasted spans or those provided with heavy timber floors, the effect of these irregularities can be diminished and impact stresses correspondingly decreased.

### Conclusions

From the above analysis it is seen that the "live-load effect" of a smoothly running load is always small. Under the most unfavorable condition it will not exceed 10 per cent, and can therefore be neglected.

The "impact effect of the balance weights" of the locomotive driving wheels may become of practical importance, especially under conditions involving resonance. The most severe impact effect will be obtained in the shortest spans in which resonance is likely to occur. For the assumptions made in this paper this span is about 100 ft.

The additional dynamic effect produced by irregularities in the track and flats on the wheels is of importance only for bridge parts directly subjected to the action of moving loads, and justifies the high impact factor usually applied in the design of short girders and rail bearers.

## Appendix

### General

IN DISCUSSING vibrations of bridges the problem can be simplified by considering the bridge as a beam of uniform cross-section simply supported at the ends. The general form of de-

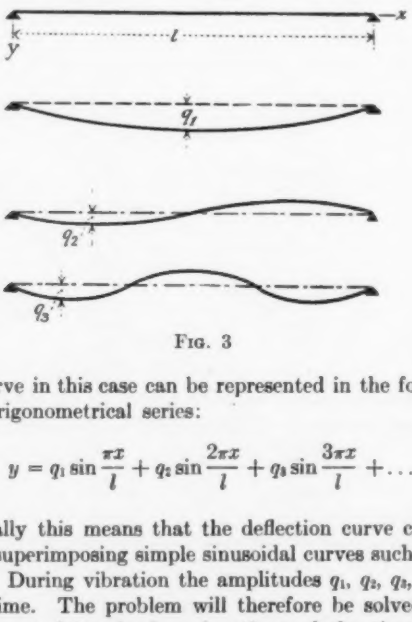


Fig. 3

flection curve in this case can be represented in the form of the following trigonometrical series:

$$y = q_1 \sin\frac{\pi x}{l} + q_2 \sin\frac{2\pi x}{l} + q_3 \sin\frac{3\pi x}{l} + \ldots\ldots [11]$$

Geometrically this means that the deflection curve can be obtained by superimposing simple sinusoidal curves such as shown in Fig. 3. During vibration the amplitudes $q_1, q_2, q_3, \ldots$ vary with the time. The problem will therefore be solved if these amplitudes are determined as functions of the time. In the following discussion of the problem we shall consider the quantities $q_1, q_2, q_3, \ldots$ as *generalized coordinates* of the vibrating beam and shall use general expressions for kinetic and potential energy expressed in terms of these quantities. The potential energy in this case will be the energy of bending, which can be calculated from the following known equation:

$$V = \frac{EI}{2}\int_0^l \left(\frac{d^2y}{dx^2}\right)^2 dx \ldots\ldots [12]$$

Substituting series [11] for $y$ in this equation and taking into consideration the fact that:

$$\int_0^l \sin\frac{m\pi x}{l}\sin\frac{n\pi x}{l}\,dx = 0 \text{ when } m \neq n$$

$$\int_0^l \sin^2\frac{m\pi x}{l}\,dx = \frac{l}{2}$$

we obtain

$$V = \frac{EI}{2}\left(\frac{\pi^4}{2l^3}q_1^2 + \frac{2^4\pi^4}{2l^3}q_2^2 + \frac{3^4\pi^4}{2l^3}q_3^2 + \ldots\right)$$

$$= \frac{EI\pi^4}{4l^3}\sum_{i=1}^{i=\infty} i^4 q_i^2 \ldots\ldots [13]$$

In calculating the kinetic energy of the vibrating beam the following symbols will be used:

$A$ = cross sectional area of the beam

$\gamma$ = weight of the material per unit volume.

Then the kinetic energy of one element $dx$ of the beam will be

$$\frac{A\gamma}{2g}\dot{y}^2\,dx$$

and the complete kinetic energy of the vibrating beam becomes:

$$T = \frac{A\gamma}{2g}\int_0^l \dot{y}^2\,dx \ldots\ldots [14]$$

Substituting series [11] for $y$ and taking into consideration that $q_1, q_2, \ldots$ are functions of the time, we obtain:

$$T = \frac{A\gamma}{2g}\int_0^l \left(\dot{q}_1 \sin\frac{\pi x}{l} + \dot{q}_2 \sin\frac{2\pi x}{l} + \dot{q}_3 \sin\frac{3\pi x}{l} + \ldots\right)^2 dx$$

or, after integration,

$$T = \frac{A\gamma}{2g}\left(\dot{q}_1^2\frac{l}{2} + \dot{q}_2^2\frac{l}{2} + \dot{q}_3^2\frac{l}{2} + \ldots\right) = \frac{A\gamma l}{4g}\sum_{i=1}^{i=\infty}\dot{q}_i^2 \ldots [15]$$

To obtain the quantities $q_1, q_2, q_3, \ldots$ we shall use now Lagrange's general equations of dynamics which have the following form:

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{q}_i} - \frac{\partial T}{\partial q_i} + \frac{\partial V}{\partial q_i} = Q_i \ldots\ldots [16]$$

In this equation $\frac{\partial T}{\partial q_i}$ and $\frac{\partial V}{\partial q_i}$ represent, respectively, the partial derivative of the kinetic energy with respect to any coordinate $q_i$ and the partial derivative with respect to the corresponding velocity $\dot{q}_i$. $Q_i$ represents the generalized disturbing force corresponding to the coordinate $q_i$. In order to find $Q_i$ in any particular case it is only necessary to give to the coordinate $q_i$ an infinitely small increase $\delta q_i$ and to calculate the work $\delta W$ produced by the external forces during the increase $\delta q_i$ of the coordinate $q_i$. $Q_i$ will thus be found from the equation

$$Q_i = \frac{\delta W}{\delta q_i} \ldots\ldots [17]$$

Several examples of the calculation of the generalized force $Q_i$ will be shown later.

Substituting the expressions for $T$ and $V$ in Equation [16] the following differential equation of motion will be obtained for each coordinate $q_i$:

$$\frac{A\gamma l}{2g}\ddot{q}_i + \frac{EI\pi^4 i^4}{2\,l^3} q_i = Q_i$$

or

$$\ddot{q}_i + \frac{a^2 i^4 \pi^4}{l^4} q_i = \frac{2g}{A\gamma l} Q_i \qquad [18]$$

in which

$$a^2 = \frac{EIg}{A\gamma} \qquad [19]$$

The differential equation [18] is a linear differential equation with constant coefficients which may easily be solved provided the force $Q_i$ is known as a function of time. The complete integral can then be represented in the following form:

$$q_i = A_i \cos\frac{i^2\pi^2 at}{l^2} + B_i \sin\frac{i^2\pi^2 at}{l^2} + \frac{l^2}{i^2\pi^2 a}\,\frac{2g}{\gamma Al}\int_0^t Q_i \sin\frac{i^2\pi^2 a}{l^2}(t - t_1)dt_1 \qquad [20]$$

The first two terms in this solution represent the free vibration determined by the initial conditions, while the third term represents the vibration produced by the disturbing force $Q_i$. The period of the natural vibration will thus be

$$T_i = \frac{2\pi l^2}{i^2\pi^2 a} = \frac{2\,l^2}{i^2\pi}\sqrt{\frac{A\gamma}{EIg}} \qquad [21]$$

and its frequency is therefore

$$f_i = \frac{1}{T_i} = \frac{i^2\pi}{2l^2}\sqrt{\frac{EIg}{A\gamma}} \qquad [22]$$

This natural vibration corresponds to the coordinate $q_i$. The corresponding deflection curve (Fig. 3) has $i$ waves and $i - 1$ nodes. It is seen that with increase of the number of waves $i$ the frequency increases as $i^2$. Vibrations produced by disturbing forces will now be considered.

### Pulsating Force

As an example let us consider first the case of a pulsating force $P = P_0 \sin nt_1$ applied at a distance $c$ from the left support (see Fig. 4) and having the period $2\pi/n$. In order to obtain a generalized force $Q_i$ in Equation [18] for this case let us assume that a small increase $\delta q_i$ is given to a coordinate $q_i$. The corresponding deflection of the beam, from [11], will be $\delta y = \delta q_i \sin\frac{i\pi x}{l}$, and the work done by the external force $P$ on this displacement is:

$$\delta W = P\delta q_i \sin\frac{i\pi c}{l}$$

Then from Equation [17]

$$Q_i = P\sin\frac{i\pi c}{l} = P_0 \sin\frac{i\pi c}{l}\sin nt_1 \qquad [23]$$

Substituting in Equation [20] and considering only the third term representing vibration produced by the pulsating force, we obtain:

$$q_i = \frac{2g}{\gamma A}P_0 \sin\frac{i\pi c}{l}\left[\frac{l^3}{i^4\pi^4 a^2 - n^2 l^4}\sin nt - \frac{nl^5}{i^2\pi^2 a(i^4\pi^4 a^2 - n^2 l^4)}\sin\frac{i^2\pi^2 at}{l^2}\right] \qquad [24]$$

Substituting in Equation [11], we have

$$y = \frac{2gP_0 l^3}{\gamma A}\sum_{i=1}^{i=\infty}\frac{\sin\frac{i\pi c}{l}\sin\frac{i\pi x}{l}}{i^4\pi^4 a^2 - n^2 l^4}\sin nt - \frac{2gn\,P_0 l^5}{\gamma A\pi^2 a}\sum_{i=1}^{i=\infty}\frac{\sin\frac{i\pi c}{l}\sin\frac{i\pi x}{l}}{i^2(i^4\pi^4 a^2 - n^2 l^4)}\sin\frac{i^2\pi^2 at}{l^2} \qquad [25]$$

It is seen that the first series in this solution is proportional to $\sin nt$. It has the same period as the disturbing force and represents forced vibrations of the beam. The second series represents free vibrations of the beam produced by the application of the force. The latter type of vibrations will be gradually

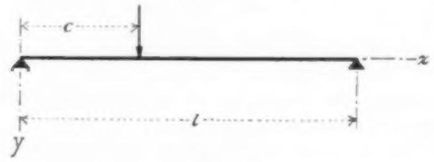


Fig. 4

damped out because of friction, internal hysteresis, etc. Hence, only the forced vibrations, given by the equation

$$y = \frac{2gP_0 l^3}{\gamma A}\sum_{i=1}^{i=\infty}\frac{\sin\frac{i\pi c}{l}\sin\frac{i\pi x}{l}}{i^4\pi^4 a^2 - n^2 l^4}\sin nt \qquad [26]$$

are of practical importance.

If the pulsating force $P$ is varying very slowly, $n$ is a very small quantity and $n^2 l^4$ can be neglected in the denominator of the series [26]. In such cases the expression for $y$ becomes:

$$y = \frac{2gPl^3}{\gamma A\pi^4 a^2}\sum_{i=1}^{i=\infty}\frac{1}{i^4}\sin\frac{i\pi c}{l}\sin\frac{i\pi x}{l} \qquad [27]$$

or, by using Equation [19],

$$y = \frac{2Pl^3}{EI\pi^4}\sum_{i=1}^{i=\infty}\frac{1}{i^4}\sin\frac{i\pi c}{l}\sin\frac{i\pi x}{l} \qquad [28]$$

This expression represents the statical deflection of the beam produced by the load $P$.[9] In the particular case, when the force $P$ is applied at the middle, $c = l/2$, and we obtain

$$y = \frac{2Pl^3}{EI\pi^4}\left(\sin\frac{\pi x}{l} - \frac{1}{3^4}\sin\frac{3\pi x}{l} + \frac{1}{5^4}\sin\frac{5\pi x}{l} + \ldots\right) \qquad [29]$$

This series converges rapidly, and a satisfactory approximation for the deflections will be obtained by taking the first term only. In this manner we find for the deflection at the middle,

$$\left(y\right)_{x = l/2} = \frac{2Pl^3}{EI\pi^4} = \frac{Pl^3}{48.7EI}$$

The error of this approximation is thus about 1.5 per cent. Denoting by $\alpha$ the ratio of the frequency $n/2\pi$ of the disturbing force to the frequency $a\pi/2l^2$ of the fundamental type of free vibration, we have:

$$\alpha = \frac{nl^2}{a\pi^2}$$

[9] See "Applied Elasticity," by S. Timoshenko and J. M. Lessells, p. 131.

and the series [26], representing the forced vibrations, becomes

$$y = \frac{2P_0\, l^3 \sin nt}{EI\pi^4} \sum_{i=1}^{i=\infty} \frac{\sin \frac{i\pi c}{l} \sin \frac{i\pi x}{l}}{i^4 - \alpha^2}$$

If the pulsating force is applied at the middle, we obtain

$$y = \frac{2P_0 \sin ntl^3}{EI\pi^4}\left[\frac{\sin \frac{\pi x}{l}}{1-\alpha^2} - \frac{\sin \frac{3\pi x}{l}}{3^4-\alpha^2} + \frac{\sin \frac{5\pi x}{l}}{5^4-\alpha^2} + \ldots\right] \ldots [30]$$

For small values of $\alpha$ the first term of this series represents the deflection with good accuracy. By comparing [30] with [29] it can be concluded that the ratio of the dynamical deflection to the statical deflection is approximately equal to

$$\frac{1}{1-\alpha^2} \ldots\ldots\ldots\ldots [31]$$

If, for instance, the frequency of the disturbing force is one-fourth that of the fundamental mode of vibration, the dynamical deflection will be about 6 per cent greater than the statical deflection.

Since problems involving small vibrations of beams are represented by *linear* differential equations, the principle of superposition holds. Hence, if we have several pulsating forces acting on the beam the resulting vibration will be obtained by superimposing the vibration produced by the individual forces. The case of continuously distributed pulsating forces also can be solved in the same manner; the summation has only to be replaced by an integration along the length of the beam. Assume, for instance, that the beam is loaded by a uniformly distributed pulsating load of the intensity

$$q = q_0 \sin nt$$

Such a condition of loading will exist, for instance, in a locomotive side rod due to the action of variable bending inertia forces. In order to solve this case, $q_0 dc$ should be substituted for $P_0$ in Equation [26] and the integration carried out with respect to $c$, the limits being $c = 0$ and $c = l$. In this manner, there is obtained:

$$y = \frac{4gq_0 l^4}{\gamma A\pi} \sum_{i=1,3,5\ldots}^{i=\infty} \frac{\sin \frac{i\pi x}{l} \sin nt}{i(i^4\pi^4 a^2 - n^2 l^4)} \ldots\ldots\ldots [32]$$

If the frequency of the load is very small in comparison with the frequency of the fundamental mode of vibration of the bar, we may, as before, neglect term $n^2l^4$ in the denominators of the series [32]. The equation then becomes

$$y = \frac{4ql^4}{EI\pi^5}\left[\frac{\sin \frac{\pi x}{l}}{1^5} + \frac{\sin \frac{3\pi x}{l}}{3^5} + \frac{\sin \frac{5\pi x}{l}}{5^5} + \ldots\right] \ldots [33]$$

This very rapidly converging series represents the statical deflection of the beam produced by a uniformly distributed load $q$. By taking $x = l/2$ we obtain for the deflection at the middle

$$\left(y\right)_{x=l/2} = \frac{4ql^4}{EI\pi^4}\left[1 - \frac{1}{3^5} + \frac{1}{5^5} + \ldots\right] \ldots\ldots [34]$$

If only the first term of this series be used, the error in calculating the deflection at the middle will be about $1/_4$ per cent. If the frequency of the pulsating load is not small enough to warrant the application of the statical equation, the method used in the case of a single force can be used and we shall arrive at the same conclusion as represented by Equation [31]

### Moving Constant Force

If a constant vertical force $P$ is moving along the length of a beam it produces vibrations which can be calculated without any difficulty by using the general Equation [20]. Let $v$ denote the constant velocity of the moving force and let the force be at the left support at the initial moment ($t = 0$); then at any other moment the distance of this force from this left support will be $vt_1$. In order to determine the generalized force $Q_i$ for this case, assume that the coordinate $q_i$ in the general expression [11] of the deflection curve obtains an infinitely small increase $\delta q_i$. The work done by the force $P$ due to this displacement will be

$$P\left(\delta y\right)_{x=vt_1} = P\delta q_i \sin \frac{i\pi v t_1}{l}$$

Hence, the generalized force

$$Q_i = P \sin \frac{i\pi v t_1}{l}$$

Substituting this in the third term of Equation [20], the following expression will be found for the vibration produced by the moving load:[10]

$$y = \frac{2gPl^3}{\gamma A\pi^2} \sum_{i=1}^{i=\infty} \frac{\sin \frac{i\pi x}{l}}{i^2(i^2\pi^2a^2 - v^2l^2)} \sin \frac{i\pi vt}{l}$$

$$- \frac{2gPl^4 v}{\gamma A\pi^3 a} \sum_{i=1}^{i=\infty} \frac{\sin \frac{i\pi x}{l}}{i^3(i^2\pi^2a^2 - v^2l^2)} \sin \frac{i^2\pi^2 at}{l^2} \ldots\ldots [35]$$

The first series in this solution represents the forced vibrations, and the second series the free vibrations of the beam.

If the velocity $v$ of the moving force be very small, we can put $v = 0$ and $vt = c$ in the solution above; then

$$y = \frac{2gPl^3}{\gamma A\pi^4 a^2} \sum_{i=1}^{i=\infty} \frac{1}{i^4} \sin \frac{i\pi c}{l} \sin \frac{i\pi x}{l}$$

This is the statical deflection of the beam produced by the load $P$ applied at a distance $c$ from the left support—see Equation [27]. By using the notation

$$\alpha^2 = \frac{v^2l^2}{a^2\pi^2} \ldots\ldots\ldots\ldots [36]$$

the part of the general solution [35] representing forced vibrations becomes

$$y = \frac{2Pl^3}{EI\pi^4} \sum_{i=1}^{i=\infty} \frac{\sin \frac{i\pi x}{l} \sin \frac{i\pi vt}{l}}{i^2(i^2 - \alpha^2)} \ldots\ldots\ldots [37]$$

It is interesting to note that the expression for this deflection is identical with that for the statical deflection of a beam[11] on which, in addition to the lateral load $P$ applied at a distance $c = vt$ from the left support, a longitudinal compressive force $S$ is acting,

[10] This problem is of practical interest in connection with the study of bridge vibrations. The first solution was obtained by A. N. Kriloff, member of the Academy of Sciences in St. Petersburg; see *Mathematische Annalen*, vol. 61 (1905), and also the author's paper in the "Bulletin of the Polytechnical Institute in Kiew" (1908), German translation in *Zeit. f. Math. u. Phys.*, vol. 59 (1911). Prof. C. E. Inglis in the Proc. of the Inst. of Civil Engineers, vol. 218 (1924), London, came to the same results.

[11] See "Applied Elasticity" mentioned above, p. 163. By using the known expression for the statical deflection curve, the finite form of the function, from which the series [37] has its origin, can be obtained.

the value of $S$ being such that

$$S : S_{cr} = \frac{Sl^2}{EI\pi^2} = \alpha^2 \ldots\ldots\ldots\ldots\ldots [38]$$

Here $S_{cr}$ denotes the known critical load which will cause buckling of the beam. From Equations [37] and [38] we obtain

$$\frac{Sl^2}{EI\pi^2} = \frac{v^2l^2}{a^2\pi^2}$$

or

$$S = \frac{v^2A\gamma}{g} \ldots\ldots\ldots\ldots\ldots\ldots [39]$$

The effect of this force $S$ on the statical deflection of the beam loaded by the force $P$ is therefore equivalent to the effect of the velocity of the moving force $P$ on the deflection produced as a consequence of forced vibrations.

By increasing the velocity $v$ a condition can be reached where one of the denominators in the series [35] becomes equal to zero and hence resonance takes place. Assume, for instance, that

$$a^2\pi^2 = v^2l^2 \ldots\ldots\ldots\ldots\ldots\ldots [40]$$

In this case the period of the fundamental mode of vibration of the beam, equal to $\frac{2l^2}{a\pi}$, becomes equal to $\frac{2l}{v}$, and hence is twice as great as the time required for the force $P$ to pass over the beam. The denominators in the first terms of both series in Equation [35] become, under the condition [40], equal to zero, and the sum of these two terms will be

$$\frac{2gPl^3}{\gamma A\pi^2} \sin\frac{\pi x}{l} \frac{\sin\frac{\pi vt}{l} - \frac{lv}{\pi a}\sin\frac{\pi^2 at}{l^2}}{\pi^2a^2 - v^2l^2}$$

This expression has the form $\frac{0}{0}$ and may be evaluated in the usual way. It then takes the following form:

$$-\frac{Pgt}{\gamma A\pi v}\cos\frac{\pi vt}{l}\sin\frac{\pi x}{l} + \frac{Pgl}{\gamma A\pi^2v^2}\sin\frac{\pi vt}{l}\sin\frac{\pi x}{l} \ldots [41$$

Expression [41] has its maximum value when

$$t = \frac{l}{v}$$

and is then equal to

$$+\frac{Pgl}{\gamma A\pi^2v^2}\left[\sin\frac{\pi vt}{l} - \frac{\pi vt}{l}\cos\frac{\pi vt}{l}\right]_{t=\frac{l}{v}} \sin\frac{\pi x}{l} = \frac{Pl^3}{EI\pi^3}\sin\frac{\pi x}{l} \ldots [42]$$

Taking into consideration the fact that the expression [41] represents a satisfactory approximation for the dynamical deflection given by Equation [35], it can be concluded that the maximum dynamical deflection at the resonance condition, i.e., when Equation [40] is satisfied, is about 50 per cent larger than the maximum statical deflection, which is equal to $\frac{Pl^3}{48\,EI}$. It is interesting to note that the maximum dynamical deflection occurs when the force $P$ is leaving the beam. At this moment the deflection under the force $P$ is equal to zero, hence the net work done by this force when it has just passed the length of the beam is equal to zero. In order to explain the source of the energy accumulated in the vibrating beam during the passing over of the force $P$ we should assume that there is no friction and the beam produces a reaction $R$ in the direction of the normal (Fig. 5). In this case, from the condition of equilibrium it follows that there should exist a horizontal force, equal to $P\frac{dy}{dx}$. The work done by this force during its passage along the beam will be

$$W = -\int_0^{l/v} P\left(\frac{dy}{dx}\right)_{x=vt} v\,dt$$

Substituting expression [41] for $y$ we obtain

$$W = -\frac{P^2g}{\gamma A\pi v^2}\int_0^{l/v}\left(\sin\frac{\pi vt}{l} - \frac{\pi vt}{l}\cos\frac{\pi vt}{l}\right)\cos\frac{\pi vt}{l}\,v\,dt$$
$$= \frac{P^2gl}{\gamma A\pi^2v^2} \times \frac{\pi^2}{4}$$

or, by taking into consideration the relations given by Equations [40] and [19], we obtain a value for the work done equal to:

$$W = \frac{\pi^2}{4}\frac{P^2l^3}{EI\pi^4}$$

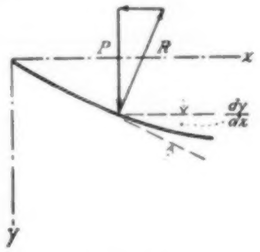


Fig. 5

This amount of work is approximately equal[12] to the amount of the potential energy of bending of the beam at the moment $t = l/v$. In the case of bridges the time necessary to cross the bridge is usually large in comparison with the period of the fundamental type of vibration; hence the quantity $\alpha^2$, given by Equation [9] is small. Then by taking only the first term in each series of Equation [35] and assuming that in the most unfavorable case the amplitudes of the forced and free vibration are added directly, we obtain for the maximum deflection

$$y_{max.} = \frac{2gPl^3}{\gamma A\pi^2}\left(\frac{1}{\pi^2a^2 - v^2l^2} + \frac{vl}{a\pi}\frac{1}{\pi^2a^2 - v^2l^2}\right)$$
$$= \frac{2Pl^3}{EI\pi^4}\frac{1+\alpha}{1-\alpha^2} = \frac{2Pl^3}{EI\pi^4}\frac{1}{1-\alpha} \ldots\ldots\ldots [43]$$

This is a somewhat exaggerated value of the maximum dynamical deflection, because damping has been neglected in the above discussion.

By using the principle of superposition the solution of the problem in the case of a system of concentrated moving forces and in the case of moving distributed forces can be also solved without difficulty.[13]

## Moving Pulsating Force

Consider now the case when a pulsating force is moving along the beam with a constant velocity $v$ (Fig. 6). Such a condition may exist, for instance, when an imperfectly balanced locomotive passes over a bridge. The vertical component of the centrifugal force $P$, due to the unbalance, is

$$P\cos\omega t_1$$

where $\omega$ = the angular velocity of the driving wheel.

By using the same manner of reasoning as before, the following expression for the generalized force, corresponding to the generalized coordinate $q_i$ will be obtained:

[12] The potential energy of a beam bent by a force $P$ at the middle is $V = \frac{P^2l^3}{96\,EI}$ and $\frac{W}{V} = 2.43$. This ratio is very close to the square of the ratio of the maximum deflection for dynamical and statical conditions, which is equal to $\left(\frac{48}{\pi^3}\right)^2 = 2.38$. The discrepancy may be attributed to the higher harmonics in the deflection curve.

[13] See author's paper mentioned in footnote No. 10.

$$Q_i = P \cos \omega t_1 \sin \frac{i\pi v t_1}{l}$$

Substituting this in the third term of the general solution [20] we obtain

$$y = \frac{Pl^3}{EI\pi^4} \sum_{i=1}^{i=\infty} \sin \frac{i\pi x}{l} \left\{ \frac{\sin\left(\frac{i\pi v}{l} + \omega\right)t}{i^4 - (\beta + i\alpha)^2} + \frac{\sin\left(\frac{i\pi v}{l} - \omega\right)t}{i^4 - (\beta - i\alpha)^2} \right.$$

$$\left. - \frac{\alpha}{i}\left[ \frac{\sin \frac{i^2\pi^2 at}{l^2}}{-i^2\alpha^2 + (i^2 - \beta)^2} + \frac{\sin \frac{i^2\pi^2 at}{l^2}}{-i^2\alpha^2 + (i^2 + \beta)^2} \right] \right\} \quad .. [44]$$

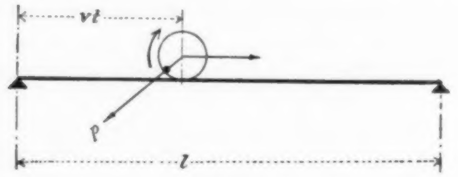

FIG. 6

where $\alpha = \frac{vl}{a\pi}$ = the ratio of the period $T = \frac{2l^2}{\pi a}$ of the fundamental type of vibration of the beam to twice the value of the time $T_1 = \frac{l}{v}$ necessary for the force $P$ to pass over the beam.

$\beta = \frac{T}{T_2}$ = the ratio of the period of the fundamental type of vibration of the beam to the period $T_2 = \frac{2\pi}{\omega}$ of the pulsating force. When the period $T_2$ of the pulsating force is equal to the period $T$ of the fundamental type of vibration of the beam $\beta = 1$ and we obtain a condition of resonance, the amplitude of vibration during motion of the pulsating force will be gradually built up and will attain its maximum at the moment $T = \frac{l}{v}$. At this instant the first term (for $i = 1$) in the series of the right-hand member of [44], which is the most important part of $y$, may be reduced to the form

$$\frac{1}{\alpha} \frac{2Pl^3}{EI\pi^4} \sin \frac{\pi x}{l} \sin \omega t$$

The maximum deflection is thus given approximately by the formula

$$\delta_{\max.} = \frac{1}{\alpha}\frac{2Pl^3}{EI\pi^4} = \frac{2T_1}{T}\frac{2Pl^3}{EI\pi^4} \quad \ldots\ldots\ldots\ldots [45]$$

Owing to the fact that in actual cases the time interval $T_1 = \frac{l}{v}$ is large in comparison with the period $T$ of the natural vibration, the maximum dynamical deflection produced by the pulsating force $P$ will be many times the deflection $\frac{2Pl^3}{EI\pi^4}$ which would be produced by the same force applied statically at the middle of the beam.

In the case of bridges having short spans, where the natural frequency of vibration is considerably higher than the number of revolutions per second of the driving wheels, a satisfactory approximation can be obtained by taking only the first term of the solution [44] and assuming the most unfavorable condition, namely, that at the moment $t = \frac{l}{2v}$ when the pulsating force arrives at the middle of the span, $\sin\left(\frac{\pi v}{l} + \omega\right)t$ and $\sin\left(\frac{\pi v}{l} - \omega\right)t$ become equal to 1 and $\sin \frac{\pi^2 at}{l^2}$ becomes equal to $-1$. Then the additional deflection, from [44], will be

$$\delta = \frac{Pl^3}{EI\pi^4}\left\{ \frac{1}{1 - (\beta + \alpha)^2} + \frac{1}{1 - (\beta - \alpha)^2} + \frac{\alpha}{(1 - \beta)^2 - \alpha^2} + \frac{\alpha}{(1 + \beta)^2 - \alpha^2} \right\}$$

$$= \frac{2Pl^3}{EI\pi^4}\left\{ \frac{1 - \alpha}{\left[1 - \beta\left(1 + \frac{\alpha}{\beta}\right)\right]\left[1 + \beta\left(1 - \frac{\alpha}{\beta}\right)\right]} \right\} \quad \ldots. [46]$$

The application of this equation is shown in the paper proper.

## Discussion

A. I. LIPETZ.[14] The writer has been interested in locomotive counterbalances for a long time, chiefly from the standpoint of effect of the excess counterbalance on rails, and has found in comparing actual stress records obtained from special recording apparatus that the difference between the steam and electric locomotive is not so high as one might expect. The electric locomotive is supposed to be perfectly balanced, and it should not have this additional impact effect on bridges which Professor Timoshenko mentions. In comparing the recorded figures it is difficult to account for the small difference, for in heavy locomotives counterbalances sometimes have very considerable excess balances. It is possible that the time element has an effect. Perhaps Professor Timoshenko will explain whether or not the dynamic force, if its translation and time element are taken into consideration, would total all our results so as to make the dynamic effect negligible.

At high speeds the excess counterbalance may give a theoretically larger dynamic augment, but the time of its action is shorter and the section of highest stress travels more rapidly. In other words, it is possible that the higher the speed of the locomotive the lesser the effect relatively, and this may explain why locomotives with very heavy excess counterbalances are running safely and cause few rail breakages, whereas a slight increase in static weight per axle seems to cause breakages.

GEORGE E. THACKRAY.[15] Having been interested in rails for many years, the writer has had occasion at various times to notice the effects of unbalanced drivers on railway roadbeds. There have been many examples in this country of medium- and heavy-weight rails being deflected and bent at distances apart about equal to the circumference of a locomotive driving wheel, due to the action of the unbalanced moving parts.

It is impossible to balance a locomotive driver perfectly, because of the combined unbalancing effects of the reciprocating and revolving connecting rods, the revolving side rods, and the horizontally reciprocating piston, piston rod, and crosshead, as these parts have differing motions, all of which cannot be counterbalanced by the usual revolving weights on the driving wheels.

Referring now to the remarks of Mr. Lipetz regarding the damping of the vibrations of a bridge, it seems that the vibration of a bridge as a whole, to a certain extent, determines some of the stresses which would be found in some of its members. How-

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ever, in bridges of long spans on which one train load is two heavy locomotives followed by 6000 lb. per ft. or more, the inertia of the load of the train itself would cause a very appreciable dampening upon the vibration of the bridge as a whole.

The greatest effect of such a moving load, with respect to vibration and impact, would be upon the members which are directly under or near the rails, such as the floor beams and stringers, and much less upon a long and heavy bridge as a whole.

G. M. Eaton.[16] Since the dynamic augment comes first on one side of the locomotive and then on the other, there must be a turning tendency introduced, and the bridge being weaker laterally and torsionally than it is vertically, there would seem to be danger from this source. Perhaps Professor Timoshenko will go into this matter in his closure.

H. W. Fitch.[17] Observations in the shops show that frequently there are engines which are so far out of proper balance that it seems quite possible to produce the effects which Mr. Thackray has spoken of; that is, permanent deformation of the rails at intervals equal to the circumference of the driver. There seems to be a practical problem there for the railroads in properly maintaining engines which have been correctly counterbalanced upon leaving the builders.

William Elmer.[18] The comments of Mr. Fitch recall an experience when the writer was master mechanic at one of our shops. A certain locomotive came in for its general repairs, and upon examining the main drivers on the left side it was found that there was no counterbalance whatever. Lead had been poured into the space provided, but unfortunately the plugs which closed the holes had worked out, allowing the weights to become loose inside the retaining casing. The lead then had, apparently, due to the countless revolutions of the wheel, become completely disintegrated and worked out of the holes. The locomotive had been running back and forth over the road with absolutely no counterbalance whatever on the driving wheel.

During our tests at the St. Louis Exposition, it was the practice to run a wire underneath the main driver in order to get some indication of the counterbalance performance. It was found that some of the engines on the test plant when they were up to speed showed no weight whatever on the driving wheels at the point where the dynamic augment was at a minimum. Of course, at the opposite point of the revolution there was a marked flattening of the wire, indicating a very high increase in the dynamic augment.

The Author. Referring to the remarks of Mr. Lipetz, the author would state that the period of free vibration of a rail as a bar on an elastic foundation is very short in comparison with the time of one revolution of the locomotive wheel. Under such conditions the stresses and deflections produced by counterbalance weights will be nearly the same as those calculated from statical considerations. It is also an established fact that the *endurance limit* of steel under reversal of stresses is the same for 200 and for 2000 cycles per minute. An increase in endurance limit becomes noticeable only at very high frequency, such as 30,000 cycles per minute.

In comparing the stresses produced by static weights with those due to excess counterbalances, it is necessary to keep in mind that static weights produce deflections convex downward under the wheel and convex upward in the interval between two wheels, so that in each individual cross-section of the rail the stresses produced by static weights are reversed several times during one passage of the locomotive. The counterbalance weights produce additional stress in certain fixed sections of the rail, the distance between which is equal to the circumference of the wheel. In consecutive rides these overstressed sections will not coincide, hence the effect of such additional stress on fatigue of steel will be less than that produced by static weights.

Referring to the remark of Mr. Eaton, the author would state that the method developed in the paper can be used also in investigating lateral vibrations of bridges. These vibrations may be of great practical importance, the bridges usually being weaker laterally and torsionally than they are vertically.

Mr. Thackray, in his discussion, makes a remark on the appreciable dampening effect which is produced on the vibration of the bridge by the inertia of the weight of the train. Such a dampening effect is an established fact. It has been proved by experiments of the Indian Railway Bridge Committee mentioned in the paper.

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# Electric Interlocking System

## Installation by the Boston & Albany Railroad at Its New Station in Springfield, Mass., Centralizes Control of All Switches and Signals

By R. J. Cullen,[1] Boston, Mass.

Coincident with the construction of a new and modern station at Springfield, Mass., which included a rearrangement of tracks to provide adequate and efficient operation for handling the ever-increasing freight and passenger traffic at this point, an electric interlocking system was installed by the Boston & Albany Railroad which centralized the control of all switches and signals at the east and west ends of the station in one plant.

The safe, expeditious, and economical handling of railway traffic at junctions and terminals on the vast railway systems of the country led to the development of interlocking plants that provide a dependable method of operating switches and signals from a central point under the control of levers in an interlocking machine. Traffic thus controlled is not only greatly expedited, but train operation, even when conducted under the most intense operating conditions, is handled with an increased factor of safety.

An interlocking plant is an assemblage of switches, signals, and other appliances operated from the levers of an interlocking machine. An interlocking machine is an arrangement of switch and signal levers in a frame so interlocked that their movements must succeed each other in a predetermined order.

The features of vital importance in any system of electric interlocking are those that are designed to give the greatest measure of safety together with facility of operation. The features most important to safety are:

1 The means provided to insure coordination between the controlling levers in the interlocking machine.

2 The means provided to insure coordination between the levers and the switches, signals, or other functions controlled by them.

3 The means provided for preventing unauthorized movement of switches, signals, or other controlled functions.

4 The means provided for preventing the operation of the controlling levers except when it is safe and proper to do so.

The feature most important to provide facility of operation is the means to inform the operator at the signal station as to what is taking place on the roadway.

### Interlocking Machine

The interlocking machine, which is placed in the operating room of the signal station (Fig. 1) 45 ft. above the track level, consists of a 248-lever frame, with 185 working levers controlling 77 signals, 33 single switches, 17 movable point frogs, 34 double slip switches, 1 check lock lever, and 1 derail. An interlocking machine is shown in Fig. 2.

The levers, which are of the pistol-grip type, equipped with all necessary controllers and connections, are in a common frame. One lever is provided for the operation of each switch and signal. To operate the two switches of a crossover, two levers, one of which is equipped with all connections and the other minus hand grip, are fastened by a rigid connection to operate as one lever. With this arrangement the two ends of a crossover are operated simultaneously in the same length of time as is required to operate a single switch.

In explanation of the detail operation of a switch lever its movement can be considered as being divided into three parts, the preliminary, intermediate, and final. The preliminary and intermediate parts, however, usually constitute one continuous movement. In the preliminary movement of the lever the locking tappet is moved through one-half of its stroke, this movement locking all levers which conflict with the new position of the lever in question; in this movement no change whatsoever is made in the operating circuits. During the intermediate part of the travel the tappet bar remains stationary and the circuits for the operation of the function are set up. The lever is held at this point through the mechanical design of the lever proper, until such time as the function has moved to a corresponding position, which effects the release of the lever and permits its final movement. During this final movement the stroke of the locking tappet is completed, thereby unlocking all levers which do not conflict with the new position of the operated lever. The movement of the lever from reverse to normal is performed in a similar manner to that described.

The movement of the signal lever is identical with that of the switch lever except that it is not necessary to check the final position of the lever during reverse movement with the position of its controlled function.

The first important safety feature, that of insuring coordination between the controlling levers of the interlocking machine, is accomplished through the design of the machine so that no lever can be moved from a given position if any other lever that is mechanically interlocked therewith is in such a position that its controlled function will conflict with the function to be moved; and further, the mechanical locking is so constructed that the operation of a given lever from its position locks all conflicting levers against movement until such time as it is proper for them to be released. This feature is accomplished by the mechanical locking which is inserted between the controlling levers.

The mechanical locking insures that before a signal can be given for any route all switch and derail functions in the route are thrown to the proper positions and locked in that position and all opposing signals are in the stop position. No changes can be made in the position of any of these functions until the lever controlling the signal displayed at proceed has been replaced to its full normal position. This locking mechanism is mounted on locking plates securely attached to the front of the machine frame. The plates are designed with vertical and horizontal slots. The locking tappets, one of which is attached to each lever, are fitted each in the vertical slot directly beneath its respective lever. Movement is transmitted from the lever through the medium of the tappets to the cross-locking which slides back and forth in the horizontal slots of the locking plate.

The second important safety feature insuring coordination between the levers and the switches controlled by them is secured by means of dynamic-current indication, energy for which is furnished by a momentary dynamic current generated by the switch motor of the operated function itself when, and only when, the actual operation of such function shall have been properly completed. The use of the dynamic current generated by the mo-

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Contributed by the Railroad Division and presented at the New England Industries Meeting, Boston, Mass., October 1 to 3, 1928, of The American Society of Mechanical Engineers.

mentum of the motor of the operated unit at one end of the circuit, and so giving the desired indication at the lever at the other end of the circuit, prevents the receipt of a false indication due to a cross between the wires of the circuit. As previously mentioned, no electrical indication is required during the reverse movement of a signal lever. However, in order to insure that the stop indication of a signal is displayed before the lever can be restored to its full normal position an indication must be obtained. This is secured by means of battery current controlled through a relay which directly repeats the stop indication of the signal.

The third essential safety feature, that of preventing unauthorized movements of controlled functions due to current being im-

Fig. 1 Station Tracks at West End of Layout, With Signal Station at Left, Three Top Floors

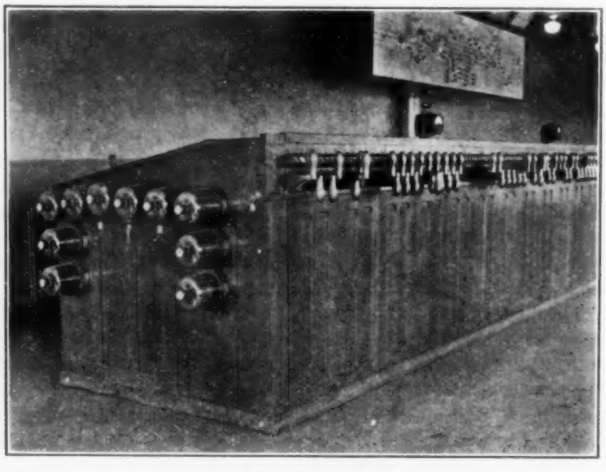

Fig. 2 Interlocking Machine

properly applied to its circuit by means of crosses or grounds, is accomplished as follows:

Each switch lever is equipped with a system known as individual cross-protection.

All switches while at rest are normally on a closed circuit of low resistance. A polarized relay of low resistance is inserted in each circuit and is mounted on the terminal board of the interlocking machine, the relay being connected in such a way that normal currents through the circuit due to manipulation of the lever flow through the relay in a direction to maintain its contact closed. However, currents improperly applied from crosses with other circuits or grounds must pass through this relay in a direction to cause its contact to open. The opening of this contact cuts off the negative energy for the switch, thereby preventing the unauthorized movement of the function. The windings of the polarized relay are so designed that its contact will open on about one-half the operating current.

The cross-protection system is installed on the closed-circuit principle, and all contacts and connections relied upon for protection are also used in operating the function, thereby securing complete check as to their integrity with every complete operation of the switch.

The unauthorized proceed indication of any signal is prevented by the placing of a shunt across the signal-operating wires by means of contacts actuated by the lever and closed only with the lever in the normal or stop position.

The fourth requisite necessary for safe operation consists of electric locking devices to guard against the possibility of a switch being operated under a train or in advance of an approaching train which has accepted a signal to proceed through the interlocking. This system of protection is known as sectional locking, sectional route locking, and approach locking. Each switch lever is equipped with a forced dropped electric lock. The coil of the lock is wound for direct-current operation at 12 volts. The lock is designed to be mounted on the top of the lever guide, locking the lever in the normal and reverse positions by means of a solenoid plunger, which, when the lock is de-energized, is forced into a notch cut on the top of the lever slide. The circuit controlling the lock coil is broken through various control relays that open or close depending upon whether one or several of the various track sections are occupied. By this means the switch levers controlling functions in any given section of track are locked in a definite position and cannot be operated by the leverman. This is called sectional locking. Sectional route locking as its name implies, is an extension or further development of

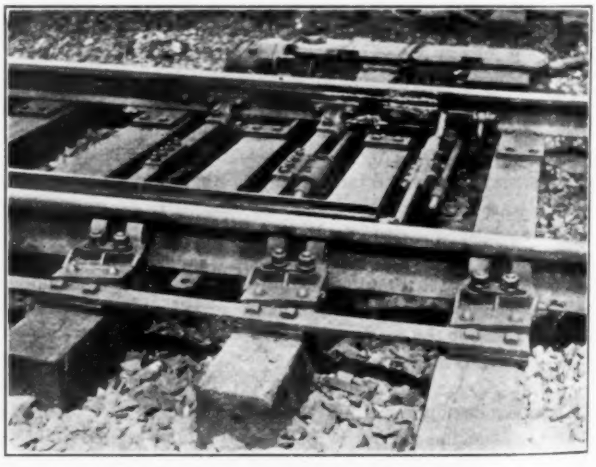

Fig. 3 Power-Operated Switch

sectional locking and route locking that, through the medium of track circuits and various control relays, locks all levers controlling switches in any route when the train passes the signal governing movements over that route. The approach locking will be explained in connection with the description of the signals.

### Switches

Each switch, movable-point frog, double slip switch, and derail is operated by a switch machine, which is a self-contained mechanism consisting of a motor, gearing, operating and locking members, pole changer, and a point detector of the over-and-locked type. Fig. 3 shows a power-operated switch.

The switch machines used (Fig. 4) are under the control of a lever in the interlocking machine and are operated by direct current at 110 volts. Machines are securely bolted to two ties and are usually placed approximately 3 feet from the gage of the nearest rail to the center line of the machine. Switch machines are rigidly maintained in their proper relation to the rail by the use of tie plates.

When the switch, in normal position, is to be operated, the first movement of the stroke of the controlling lever carries it as far as the reverse-indication position and permits current to flow, which causes the mechanism to move the switch points to the reverse position and to lock them in that position. When this movement has been completed, the circuit through the switch motor is automatically changed, disconnecting the motor from the battery and connecting it in a closed circuit including the indication magnet on the lever; at the same time the armature terminals are reversed for indication purposes, thus leaving the motor connections in proper position for the next operation. The motor, now a generator, with the momentum acquired during the operation of the switch movement generates a momentary current that energizes the indication magnet on the lever, thus permitting the final movement of the lever to be completed. The operation of the lever and function from the reverse to the normal position is accomplished in the same manner.

The complete switch operation with the final movement of the lever is accomplished in from 2 to $2^1/_2$ seconds, the indication being practically instantaneous with the completion of the switch operation.

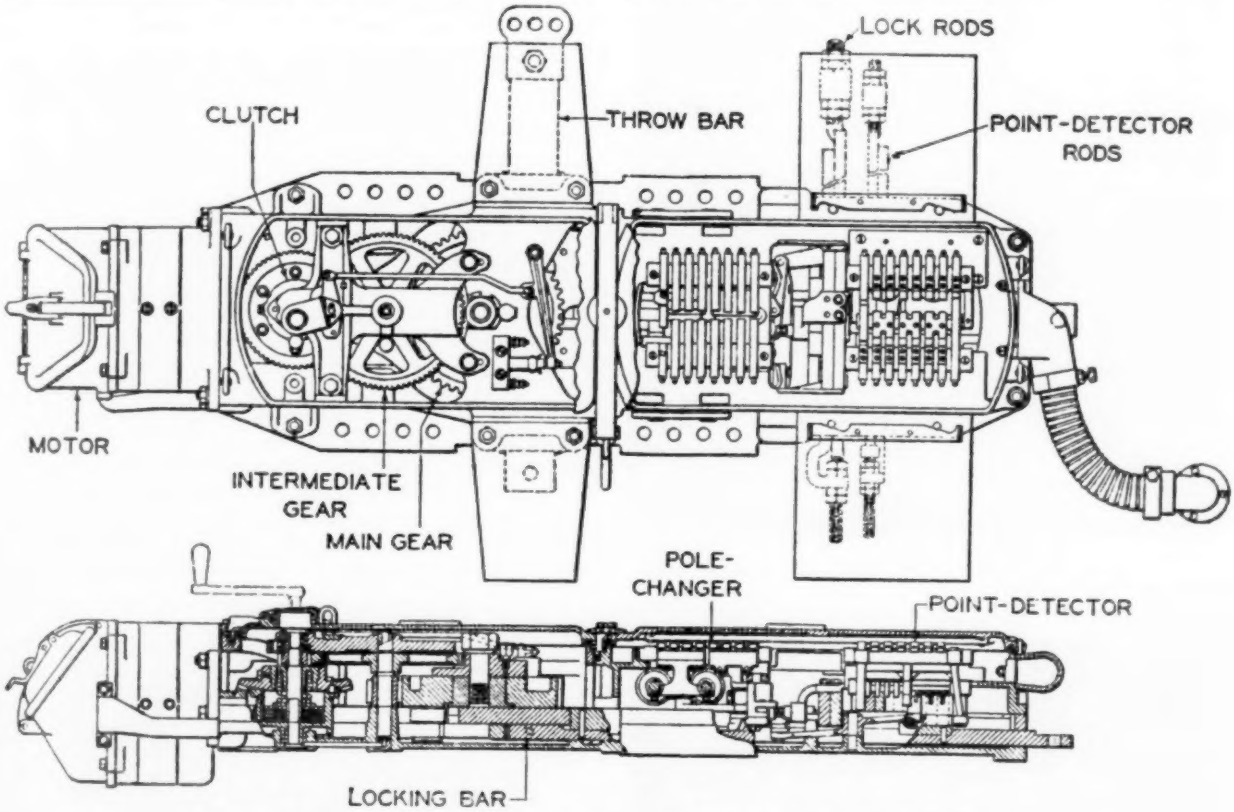


Fig. 4 Assembly of General Railway & Signal Company's Model 5A Switch Machine

### Signals

The signals are of the two- and three-indication color-light type displaying a light for both day and night indication, red being used for "Stop," yellow for "Proceed at slow speed prepared to stop," and green for "Proceed at restricted speed prepared to stop at the next signal." A three-indication color-light signal is shown in Fig. 5. Each signal is under the control of a lever in the interlocking machine and also is controlled through the switch-point detector mechanism of the switch machines in the particular route involved, thereby assuring that a proceed indication cannot be given to a train unless the switch points are in proper position and locked. The signals are equipped with the doublet-lens light units and are lighted by lamps rated at 10 volts and 20 watts. The approximate range of signals so equipped is 4000 to 5000 feet. Range is understood to mean the distance on a tangent, in bright sunlight, at which the indications are clear and distinct to a person of average eyesight. The design and the construction of this doublet-lens unit are such as to eliminate the possibility of phantom indication except those of so weak a nature as to be negligible.

Each signal controlling traffic for through movements is provided with a complete system of approach locking that prevents the changing of any switches in a given route for which the signal has been cleared for an approaching train. Should it be necessary, however, to change any route for which the proceed signal has been displayed, the approach locking may be released only after the stop indication has been displayed through the medium of clockwork time releases that can be adjusted for any time interval up to 5 minutes. This time interval is set to meet local speed conditions and to prevent the manipulation of levers that would endanger the train.

All signals not provided with approach locking are equipped with electric time-release contactors so arranged as to prevent the lever being restored to the full normal position until 10 seconds has elapsed after the signal has displayed the stop indication.

This arrangement guards against the possibility of the operator putting the signal at stop just as an engineman is passing it and changing switches in the route set-up before the track relay has opened and applied the electric locking.

### Track Circuits

The track circuit is the vital and fundamental feature of modern signaling. Upon the integrity of the track circuit rests

Fig. 5 Three-Indication Color-Light Signal

Fig. 6 West End of Track Layout Looking West From Signal Station

the proper and safe operation of the interlocking system. Its essential feature is a section of track insulated at each end from the adjoining sections of track. Each rail in this section is connected to the ones adjoining by bond wires, for the purpose of making a continuous conductor from one end of the section to the other. At one end of the insulated track section current is fed to the rail from a small transformer. Each transformer has a capacity of 75 volt-amperes with 110-volt primary and 12-volt secondary, having adjustable taps in steps of 1 volt. At the other end of the section a polyphase two-position track relay is connected to the rails. We now have a continuous closed circuit from the transformer through the rails of the track section to the relay. The presence of a pair of wheels or of a train in the section will short-circuit the transformer, shunting the current from the relay and causing it to assume the de-energized or open position. Consequently the relay is deprived by the wheels and axles of the current necessary to maintain its closed position. The track relay is equipped with the necessary contact points through which are controlled the various secondary relays for operation of the interlocking system.

The track layout at Springfield is divided into 58 separate track sections arranged to secure the necessary measure of safety combined with the maximum flexibility of operation. Parts of the track layout are shown in Figs. 6 and 7. Flexible operation of any system of interlocking depends largely upon the rapidity of operation of the individual functions and its capabilities for permitting simultaneous operation of a number of functions.

### Track and Signal Indicator

It has been stated elsewhere in this paper that the feature most important for facilitating operation in a plant of this kind is the means provided to inform the operator as to what is taking place on the roadway. This feature is provided through the medium of an illuminated track and signal indicator. The indicator, which also serves as a diagram for the numbered functions, is mounted on a steel frame suspended from the ceiling of the operating room directly over the interlocking machine (Fig. 8). This indicator is a miniature track layout showing all the track sections, switches, and signals in their respective locations. The track circuit blocks are illuminated with white electric lamps when the track section is clear, and the lamps go out automatically when the track section is occupied. For repeating the indication displayed by the signals small electric lamps are also used. These lamps are arranged to be illuminated red when the signal displays a stop indication and to show green when a proceed indication is displayed. With this arrangement a lamp failure in the track-circuit section will indicate to the operator that the section is occupied, and whether or not such indication is correct, safe operation is assured. The lamps for illuminating the indicator are supplied with current from a transformer connected to the main power supply and are directly controlled from the various track circuit sections and signal repeating relays.

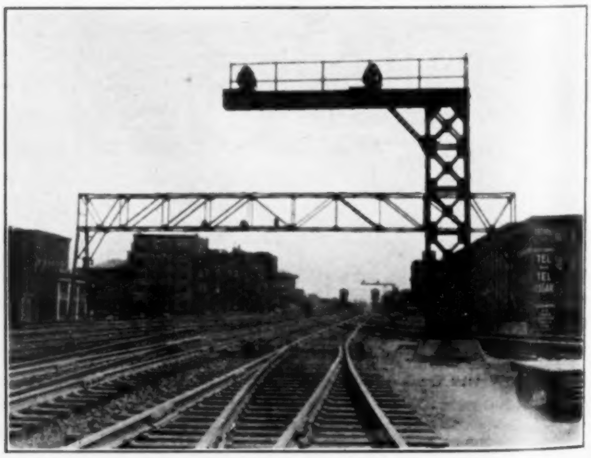

Fig. 7 West End of Track Layout Looking East From Connecticut River

### Telephone Service

In addition to the information conveyed to the operator by the indicator, complete telephone service is provided connecting with train dispatchers, station platforms, and various points on the roadway within the limits of the interlocking. The telephone service is supplemented by the telautograph system with sending and recording sets in the signal station and the dispatcher's office and with recording sets only in the station master's office, station information office, and train bulletin board in the main waiting room of the station.

### Power Supply

Power for the operation of the interlocking is taken from the city service, which supplies two-phase 60-cycle current at 440 volts. Power is distributed through the switchboard, as shown in

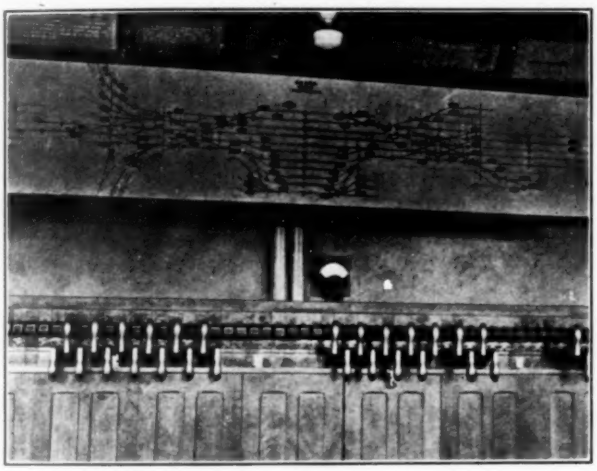

Fig. 8 Track and Signal Indicator Mounted Over Interlocking Machine in Signal Station

Fig. 9. The main battery for operating the switch machines and the low-voltage battery for operating the electric locks, secondary relays, etc., are enclosed-type lead storage batteries. The main battery consists of 60 cells of 350 ampere-hour capacity and the low-voltage battery has two sets of batteries of six cells each in multiple with a combined capacity of 700 ampere-hours. Single-phase 110-volt alternating current is supplied for the operation of the track circuits and color light signals.

The main battery is trickle-charged by a motor-generator set in duplicate. The generator is shunt-wound and supplies 750 watts at 150 volts. The low-voltage battery is also trickle-charged by a motor-generator set in duplicate. The generator is shunt-wound and supplies 750 watts at 15 volts.

In the event of a temporary failure of the commercial power furnished from the city service a d.c.-a.c. motor-generator set is provided which is automatically cut in to furnish the power to operate the interlocking. The set is operated from the main 110-volt storage battery.

### Conclusion

The features of importance in the interlocking system as installed at Springfield, the author believes, have been covered in this paper. Two of these essential features have been considered, namely, those having to do with the safety and with the facility of the system. There are of course two other features, namely, reliability and economy.

Reliability of an interlocking system is primarily dependent upon the fundamental principle underlying its operation. The principle of the system installed by the Boston & Albany, it is believed, is correct, and it therefore follows that the reliability of the system then depends upon a proper design of each and every part of the devices used to put the principle into practice.

The economy effected by a system of this kind is reflected in many ways. If the design of the apparatus is correct, resulting in

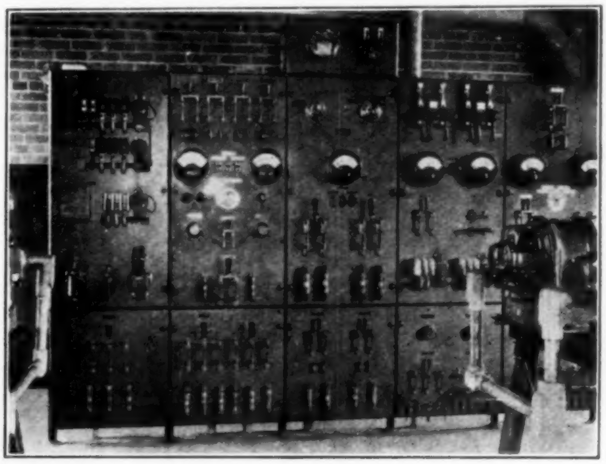

Fig. 9 Power Switchboard

long life, the cost of renewals will be relatively small. The cost of operating also shows a corresponding economy, not only by the fewer men required for an electric as compared with a mechanical system of interlocking, but also in the cost of train operation.

## Discussion

J. J. Corcoran.[3] The author mentioned phantom signal indication. In signal work this is a very important feature. The color displayed by the signal must be only that resulting from the light behind the lens. The signal is designed so that any exterior light that may be reflected from an unlighted lens and thus tend to give an improper indication, is limited as far as possible.

Another feature is that of the trickle charge which is very widely used on most of our railroads. The old-fashioned way was to charge the battery to its full capacity and then let it discharge until it reached the point as far as it was designed to go and then charge it again. This new method calls for constant float charging, thus keeping the battery at full capacity at all times so that there will always be sufficient energy to operate the system for maximum stand-by capacity.

The Author. Mr. Regan asks if this installation on the Boston & Albany has resulted in the discontinuance of two signal stations, one on either side of the Springfield station, and if we can operate the signal station with a smaller force than in the other system. In reply the author would state that the new interlocking replaces two mechanical signal stations that heretofore controlled the traffic into and through the old station. A 48-lever mechanical tower controlled the switches and signals east of the station and a 56-lever mechanical tower controlled the signal layout west of the station. These two signal stations required a force of 14 men for operation for a 24-hour period, whereas the new interlocking is operated by 9 men in the 24-hour period. This marked economy in operation effected by the new electric interlocking as compared with the old mechanical system of interlocking is further increased by a corresponding economy in the cost of train operation. A recent check-up showed that a total of approximately 1015 movements are made by this interlocking in a 24-hour period.

[3] Assistant Signal Engineer, New York Central Railroad, Lines East, Albany, New York.

# Locomotive and Freight-Car Utilization

## What the Railroads Have Accomplished in More Effective Equipment Utilization Since 1920

By C. B. Peck,[1] New York, N. Y.

The termination of Federal control of the operation of the railroads of the United States early in 1920 was the beginning of a new era of railroad operation. One of the important characteristics of the new era is the attention which is being given to effecting a more intensive utilization of every facility which enters into the production of transportation. The results are perhaps most strikingly demonstrated in the case of cars and locomotives, with which we are here concerned.

The problems involved in making the most effective use of the available supply of cars are quite different than those involved in making the most effective use of the available supply of locomotives. The car problem is much more complex and, unlike the locomotive problem, is not entirely within the control of the operating departments of the railroad, nor, indeed, entirely within the control of the railroad as a whole. The average car load is more within the control of the shipper than of the railroad, and the frequency with which each car can be made available for loading is also partially within the control of the shipper. Problems connected with interchange between railroads, particularly in keeping a suitable distribution of the supply as between regions and railroads to meet the varying seasonal demands of certain kinds of traffic, are also very complex and beyond the effective control of the carriers, acting individually.

The methods worked out by the carriers since 1920 to make the car supply serve most effectively are generally familiar to engineers interested in railroad problems. The principal features of these methods are the centralized control of car distribution through the agency of the Car Service Division of the American Railway Association in crises which require measures other than those affected by the car-service rules, the reporting of the facts pertaining to car utilization by the Car Service Division, and the opportunity for cooperative action of the railroads and the shippers through the Regional Advisory Boards.

To accomplish the utmost use of each unit of equipment, the principal objectives, so far as the operating department is concerned, are prompt movement and the heaviest practicable loading per car. The former is measured in terms of car-miles per day; the latter, in tons per loaded car. The car loading had decreased since 1920. The promptness of movement, however, as measured in miles per car-day, has markedly increased, and the result has been a progressively improving service to the public both in the promptness with which cars have been furnished for loading and the dispatch with which they have been moved to destination. Prior to and including 1920, each succeeding year of peak traffic was a year of congestion and heavy car shortages. In 1923, in which the net ton-miles handled exceeded the traffic of 1920 by 2 per cent, car shortages, although still present, were less severe in their effect. In 1926, the most recent peak year, with 8 per cent more net ton-miles than in 1920, car shortages had, practically speaking, disappeared entirely. This is a record with which the railroads and shippers alike may be proud.

So much for the character of the public service rendered by the railroads. What has been the effect on the roads themselves? What tendencies has this effort set in motion and how are they likely to affect the future? Perhaps a brief examination of the data bearing on these questions may be worth while in helping to relate to each other at least some of the factors in a situation which, in some respects, is puzzling enough.

The first factor to be considered is net ton-miles, which is the measure of the business handled. The next is the number of cars on line in which the ton-miles have been produced. The next is the number of car-miles required to handle the business, classified as loaded miles and empty miles.

In presenting the picture, I shall make as little reference as possible to the large numbers which must be used to express these various quantities in the aggregate for the Class I railroads in the United States, but since it is the trends in which we are

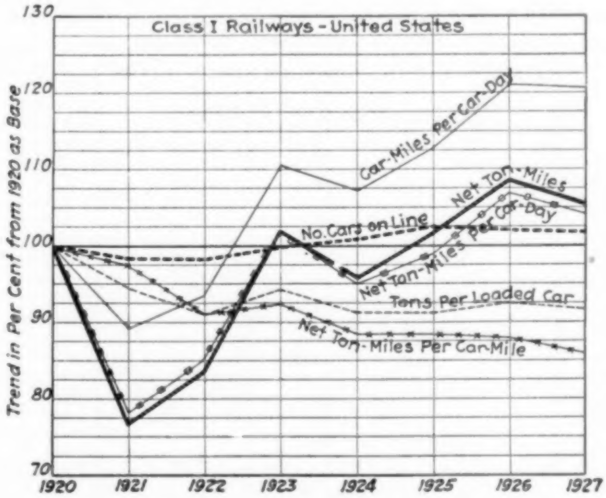


Fig. 1 Trends in Car Performance Since 1920

interested, I shall, in the main, merely indicate the rate of growth or decline since 1920. Those who are interested in the actual quantities for each year will find the data in tabular form.

In Fig. 1 is shown the trend in car utilization from 1920 as shown by the average tons of freight handled per loaded car, the average miles per car-day, and the net ton-miles per car-day. This shows the proportion to which the car load has dropped off since 1920 and how the car-miles per car-day have increased at a much greater rate than the business handled, having increased by 12 per cent in 1923 and 21 per cent in 1926, whereas the volume of business moved had increased but 2 and 8 per cent in those two years, respectively. The net ton-miles per car-day is merely an indication of the relation between the gross business handled and the aggregate supply of cars and, beyond this indication, is of little significance.

Fig. 2 shows what actually took place in producing the results indicated by the ratios in the previous diagram. The number of cars on line, which represents the ownership of the railroads plus such privately owned equipment as is actually in service on the rails of the carriers, has remained fairly constant, with a slight dropping off during 1921 and 1922 when business was light, and a gradual increase in 1925 to about 2.4 per cent more

[1] Managing Editor, *Railway Mechanical Engineer*. Assoc-Mem. A.S.M.E.

Contributed by the Railroad Division and presented at the Spring Meeting, Pittsburgh, Pa., May 14 to 17, 1928, of The American Society of Mechanical Engineers.

than in 1920, from which it has varied but slightly since that time. Loaded car-miles, of course, has followed the trend of the amount of business to be handled. But, whereas in 1923 the net ton-miles had increased only 2 per cent over 1920, the loaded car-miles had increased 7 per cent and, with 8 per cent more net ton-miles in 1926 than in 1920, the loaded car-miles was 16 per cent more than in 1920. This, of course, is the result of the decline in the average car load.

One of the most interesting points in connection with the car performance is the trend in empty car-miles. It will be seen that in 1921 when business declined materially from the preceding year, the aggregate amount of empty car mileage had increased slightly. If fell off in 1922, but not in proportion either to the amount of business or the loaded car-miles, and since that year has continued to increase steadily with the exception of an insignificant decline in 1924. In 1923, with its slight increase in business over 1920, empty car mileage had increased 18 per cent; in 1925, with practically the same volume of business, it had increased $28^1/_2$ per cent, and in 1926, had increased 40 per cent over 1920. Despite the decline in the volume of business handled in 1927, the number of empty car miles had still further increased to 42 per cent over 1920. This, then, is the explanation for the greater proportionate increase in car-miles per day than in loaded car-miles and in the maintenance of practically the same number of miles per car-day in 1927 as in 1926,

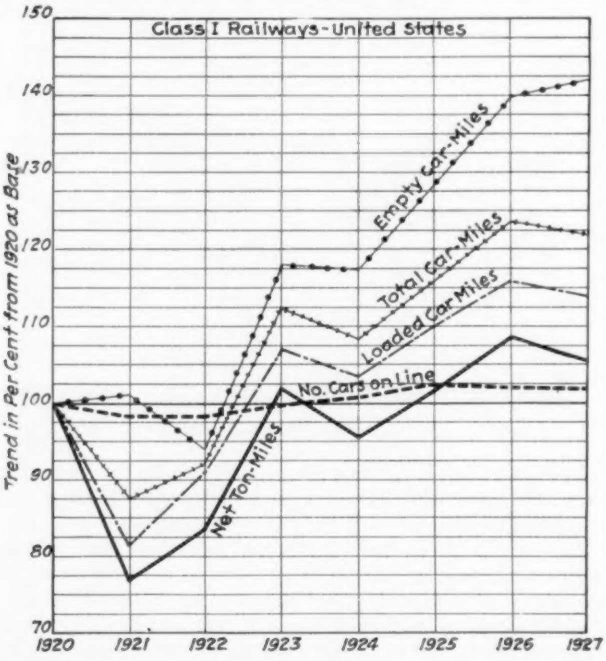


Fig. 2 Trend of Car-Miles in Relation to Net Ton-Miles Since 1920

despite a decline in business and a similar decrease in the number of loaded car-miles.

In 1920 there was an average of 47.3 empty car-miles for each 100 loaded car-miles. As the result of the marked increase in empty car-miles, there has been, with the exception of 1921, a steady increase in this ratio to 52 in 1923, to 57 in 1926, and to 59 in 1927. This is the price which the railroads have paid to make a car supply, which, in 1926, was only about two per cent greater than in 1920, handle a traffic eight per cent greater than in 1920, and to handle it without car shortages. How it was accomplished may become at least partially evident by examining the trend in the percentage of cars owned which are at home on the lines of the owning roads. This is shown in Fig. 3. The curve does not show all of the minor fluctuations reported, but does show major swings and all of the critical points in the curve. At the termination of Federal control in 1920, the freight cars of the carriers were so badly scattered that but 22 per cent were in the hands of the owners. Much the same condition had prevailed throughout the period of Federal control. This was

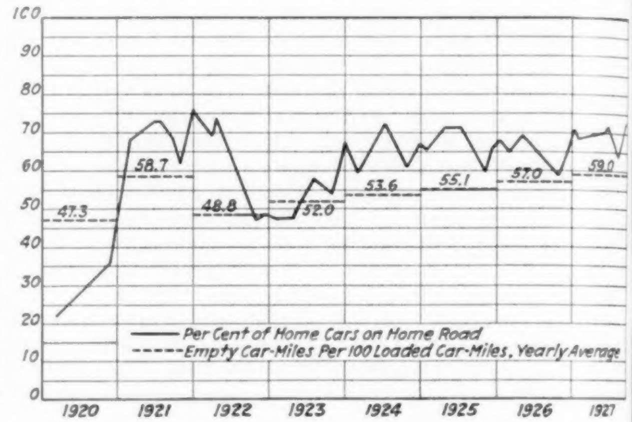


Fig. 3 The Location of Freight Cars With Respect to Ownership

followed by a tremendous home movement late in 1920 and early in 1921, to the effect of which attention has already been called in the increase in empty car mileage which took place in 1921 in spite of a severe decline in traffic. A high point was reached in January, 1922, when 75.9 per cent of the cars were in the hands of the owners. In 1922, with the coal miners' strike beginning on April 1 and the shopmen's strike beginning on July 1, the cars were again considerably scattered and but $46^1/_2$ per cent were in the hands of the owners when the downward trend was checked in November.

In the face of this unsatisfactory distribution of cars, the railroads handled the largest volume of business ever handled up to that time in the same length of time, and at the same time effected a gradual improvement in the location of the cars. During 1924 and 1925 the conditions with respect to car location remained fairly constant at a point averaging somewhere between 65 and 70 per cent, with maximums over 70 per cent and minimums not much under 60 per cent. It is worth noting that during the latter year, with a total volume of traffic practically the same as for 1923 and a fairly uniform distribution of cars, falling off slightly during the heavy traffic period in the autumn, the empty car-miles had increased materially over the number required in 1923, when a marked redistribution of equipment was effected in the face of heavy traffic.

Looking at this curve for the major trends—that is, disregarding the seasonal fluctuations—it is evident that since 1922 cars must have been promptly returned to the owning roads—loaded if possible, but without holding for loads—to maintain the relatively high percentages of cars in the hands of the owners which have prevailed since 1924.

A study of Figs. 1 and 2 shows that for the country as a whole car-miles per day implies something which I do not believe is always kept in mind when using this figure. With a total car supply which varies but slightly from year to year, car-miles per day varies in proportion to variations in total car-miles. The use of this figure, then, as a measure of overall effectiveness of car utilization places a premium on empty car-miles, which tends to swell the total without actually producing any net ton-miles of revenue movement.

As an indication of what, from a purely operating standpoint, may be considered as a measure of the efficiency with which cars are used, I believe it is permissible to divide the total number of net ton-miles moved by the total number of car-miles, empty

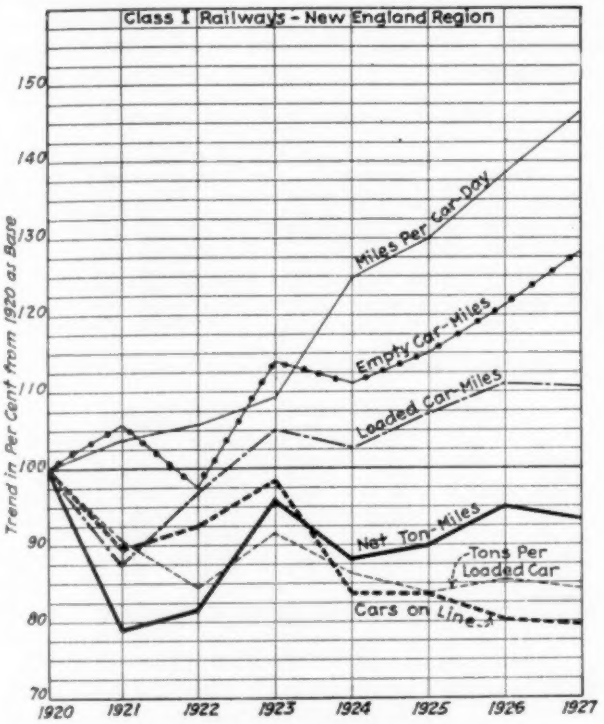


FIG. 4 CAR PERFORMANCE IN THE NEW ENGLAND REGION

and loaded combined, to see how much revenue-producing service each car-mile is rendering. The trend in this unit is shown in one of the curves on Fig. 1. It will be seen that this has been constantly declining since 1923.

This does not mean that car-miles per day is not a good unit when applied to individual railroads because it immediately reflects changes in the number of cars on the line, which do not take place when considering the roads as a whole. An accumulation of cars increases the divisor and, therefore, decreases the quotient, other conditions being equal.

How the number of cars on line affects the trend in car-miles per day is indicated in the graphs for the New England and Pocahontas regions, respectively, on Figs. 4 and 5. In the former a marked decrease in the number of cars on line from 1924 to 1927, inclusive, had a material influence in causing a proportionately much larger increase in the miles per car-day than took place in the number of car-miles. In the latter case it will be seen how an increase in the number of cars on line since 1920 has reduced the proportionate increase in car-miles per day below the proportionate increase in the number of car-miles.

While the curves show that empty car-miles are increasing much more rapidly than the aggregate service required from the total supply of freight cars, it must be remembered that what has been shown is the relationship of various trends, which does not in any way indicate the relative importance, or "weighted value" of the factors they represent in their effect on operating economy. This may, in a measure, be judged by the trend in the ratio of empty to loaded car-miles, in Fig. 3, or by the relationship between loaded car-miles and total car-miles as shown on Fig. 2.

### THE CONDITION OF FREIGHT CARS

There is another matter which must be considered before leaving the subject of freight-car utilization; that is, the conditions of the freight-car equipment during the years under consideration. Have equipment conditions been one of the causes of the splendid service results, or has the intensive service been a cause for the equipment conditions? I think it will appear that the equipment conditions have been in a measure both cause and effect.

In considering the trend in car conditions the general character of the curve in Fig. 3 showing the percentage of home cars on the owning lines should be kept in mind, remembering particularly the extremely low percentage which prevailed during 1920, the tremendous home movement late in 1920 and early in 1921, and the marked scattering of the equipment again during 1922. With this in mind, the curves on Fig. 6 will show what has been the condition of the equipment. The lower curve

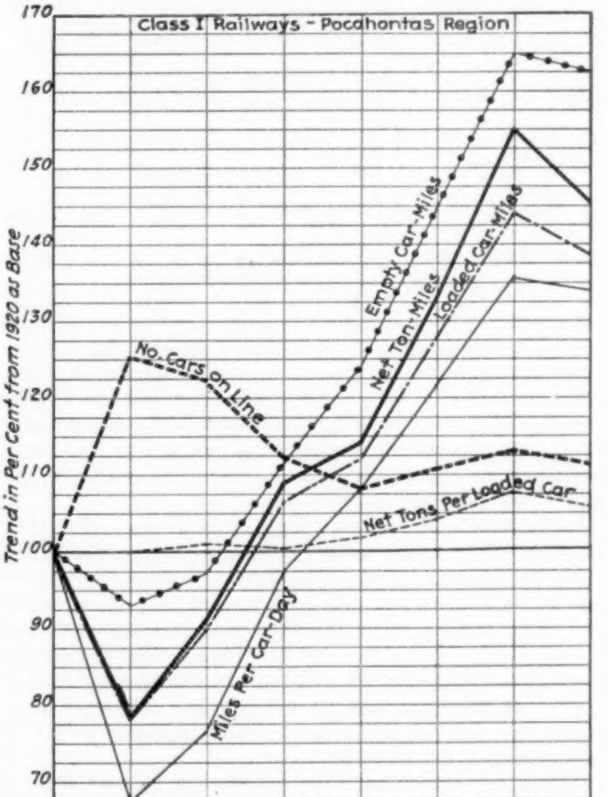


FIG. 5 CAR PERFORMANCE IN THE POCAHONTAS REGION

on this graph shows the number of hours of labor of men employed in car repairs paid for monthly by the Class I railroads. The figures are shown for a single month in each quarter of the year which I believe is sufficient to indicate the trend.

The upper curve shows the average yearly percentage of the cars owned which were unserviceable during the period. One may readily trace the effect of the 1922 strike with its accompanying scattering of the cars and disruption of the car department forces, and also the effect of the falling off of business in 1924 with the accompanying curtailment in the amount of labor devoted to car repairs. The striking thing about the situation, however, is the marked and steady decline in the percentage of bad-order

cars since 1924, with the accompanying decline in the amount of labor devoted to the maintenance and repair of cars.

It is evident that the intensive effort to rehabilitate freight cars, inaugurated in 1923, following the strike, has done more than merely to patch up the equipment, or the proportion of bad-order

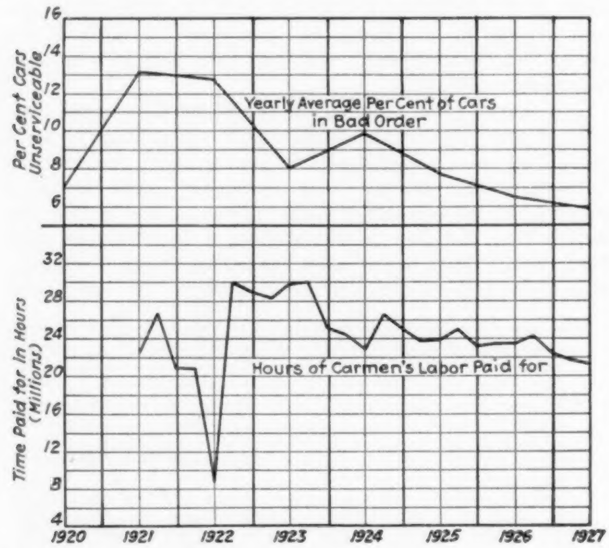


Fig. 6 Monthly Hours of Car-Repair Labor and the Percentage of Freight Cars Unserviceable

cars would not have continued to decline in the face of a decreasing amount of maintenance labor. Further evidence of this is also afforded by the fact (not shown on the diagram) that both the number of cars receiving heavy repairs and the number receiving running repairs has gradually declined through the same period. Had running repairs shown a tendency to increase, it would indicate an accumulation of deferred maintenance, but the contrary is actually the case.

The increase in the car supply available for use indicated by the decline in the percentage awaiting or under repairs has played its part in the character of the service which the railroads have been able to render. The large proportion of the cars which have at all times been on the lines of the owning roads has, in turn, been one of the causes for the constantly improving condition of the equipment. The cost of maintenance tends to decrease as the percentage of cars at home increases. Each road does a thorough job to its own cars but makes only temporary repairs to foreign cars.

Further information as to the condition of the equipment is afforded by the curves in Fig. 7. The curves at the top of the graph show the total car ownership of the Class I railroads at the end of each year and, since 1920, the average number of cars on the lines daily for each year. The lower curves, all of which are parallel to each other, have been drawn starting from different dates to show cumulatively from 1911, 1916, and 1920, respectively, the number of cars installed. It will be seen that a number of cars equal to 80 per cent of the cars owned at the end of 1926 were installed during the 15-year period from 1911, 56.7 per cent in the 10 years since 1916, and 31.2 per cent during the six years since 1920.

Attention must be called to the fact that the number of cars installed does not represent the number actually built new. This will be evident by an inspection of Fig. 8. During the years since 1920 many of these installations represent cars retired from the records of the carriers, rebuilt, in the main with betterments, and reinstated on the books of the carriers. Something of the extent to which this was done may be evident from the fact that 232,000 cars were installed in 1923, while less than 100,000 were ordered during that year, and only 180,000 had been ordered from the builders during the preceding year. Two hundred fourteen thousand cars were retired, however, in 1923, in the heavy rehabilitation program which followed the strike. A considerable percentage of these cars were undoubtedly rebuilt and reinstated.

TABLE 1 FREIGHT-CAR PERFORMANCE

| Year | Net ton-miles (000,000) | Freight car-miles (000,000) Total | Empty | Loaded | Empty in per cent of loaded | No. freight cars on line | Per cent of ownership | Per cent unserviceable |
|---|---|---|---|---|---|---|---|---|
| 1920 | 449,125 | 22,607 | 7,259 | 15,384 | 47.3 | 2,469,000 | 104.4 | 7.0 |
| 1921 | 344,343 | 19,819 | 7,335 | 12,484 | 58.7 | 2,425,000 | 103.6 | 13.2 |
| 1922 | 375,617 | 20,808 | 6,831 | 13,977 | 48.8 | 2,426,000 | 105.0 | 12.8 |
| 1923 | 457,590 | 24,993 | 8,569 | 16,424 | 52.0 | 2,463,000 | 106.3 | 8.0 |
| 1924 | 429,453 | 24,448 | 8,535 | 15,913 | 53.6 | 2,486,000 | 106.2 | 7.8 |
| 1925 | 456,265 | 26,230 | 9,323 | 16,907 | 55.1 | 2,526,000 | 106.6 | 7.7 |
| 1926 | 488,578 | 27,974 | 10,154 | 17,820 | 57.0 | 2,520,000 | 106.8 | 6.5 |
| 1927 | 474,683 | 27,791 | 10,312 | 17,479 | 59.0 | 2,509,300 | 107.0 | 5.9 |

TABLE 2 FREIGHT-CAR PERFORMANCE—AVERAGES

| Year | Average weight per car, tons | Average car capacity, tons | Net tons per loaded car | Car-miles per car-day | Net ton-miles per car-day | Net ton-miles per car-mile |
|---|---|---|---|---|---|---|
| 1920 | 20.1 | 42.4 | 29.3 | 25.1 | 498 | 19.9 |
| 1921 | 20.4 | 42.5 | 27.6 | 22.4 | 389 | 17.4 |
| 1922 | 20.5 | 43.1 | 26.9 | 23.5 | 424 | 18.1 |
| 1923 | 20.7 | 43.8 | 27.9 | 27.8 | 509 | 18.4 |
| 1924 | 20.9 | 44.3 | 27.0 | 26.9 | 472 | 17.6 |
| 1925 | 21.1 | 44.8 | 27.0 | 28.3 | 493 | 17.6 |
| 1926 | 21.4 | 45.1 | 27.4 | 30.4 | 532 | 17.5 |
| 1927 | 21.6 | . | 27.2 | 30.3 | 518 | 17.1 |

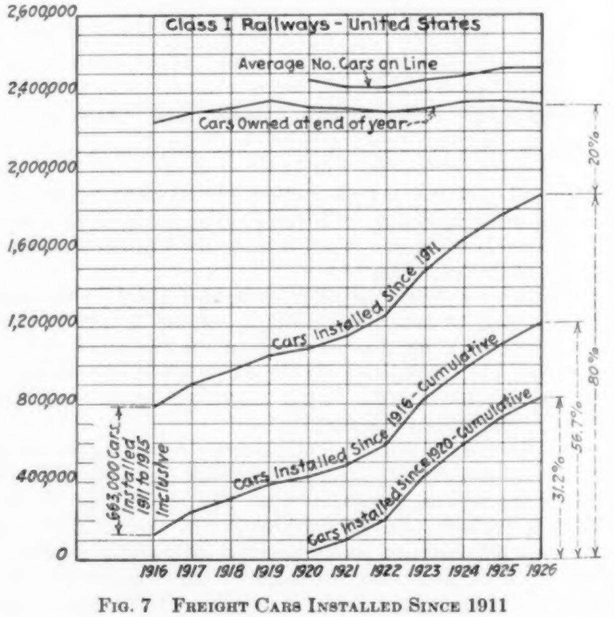


Fig. 7 Freight Cars Installed Since 1911

How far were these reinstated cars improved with betterments? It is impossible to answer this question, except in a very general way, without an actual inventory of the equipment. An indication, however, may be obtained by examining the trend in the proportion of cars of all-steel or steel underframe construction. In 1915, 52.1 per cent of all freight cars of railroad ownership were of all-steel or steel underframe construction. In 1920 this proportion had increased to 65.2 per cent, the increase having been maintained with a fair degree of uniformity throughout the five years. In 1925 this proportion had increased to 75 per cent, the trend again being fairly uniform.

The great bulk of freight cars of railroad ownership are included in two classes—box cars and open-top cars, or coal cars

In the former group are included between 46 and 47 per cent of the total ownership and in the latter, a little more than 40 per cent. In 1915, 38.6 per cent of all of the box cars owned by the Class I railroads were of all-steel or steel underframe construction mostly the latter. In 1924 this proportion had increased to 64.5 per cent and, in 1925, to 67.6 per cent. In the case of coal cars, 71.3 per cent were of steel or steel underframe construction in 1915, 89.1 per cent in 1924, and 90.5 per cent in 1925. These figures indicate a steady improvement in the character of construction which, of course, is a major factor in the ability today to maintain the equipment in a highly serviceable condition with a minimum of labor.

There is one other trend which is worth while considering before concluding our attention to the freight-car situation. That is indicated by the curves in Fig. 9 which show the rate at which the average capacity and average weight of freight cars have increased since 1920. It will be seen that the two increases have almost coincided. It will also be seen that the proportion of average car capacity which is actually utilized has declined since 1920.

Returning for a moment to Figs. 4 and 5 illustrating the trend in freight-car utilization in the New England and Pocahontas regions, respectively, one may see what a relatively small part of the potential carrying capacity of the cars is actually utilized in territories where no coal originates and how the tendency is downward under such conditions. Starting with an average car load of 24.6 tons in the New England region in 1920, it has declined to 20.7 tons in 1927. The Pocahontas Region, on the other hand, is made up of coal-carrying railroads, and car loading in this region has increased from 42.1 tons in 1925 to 45.3 tons in 1926, with a slight decline to 44.9 tons in 1927. This represents the effect of the heavy coal movement which, as the graph indicates, has grown rapidly during the past few years.

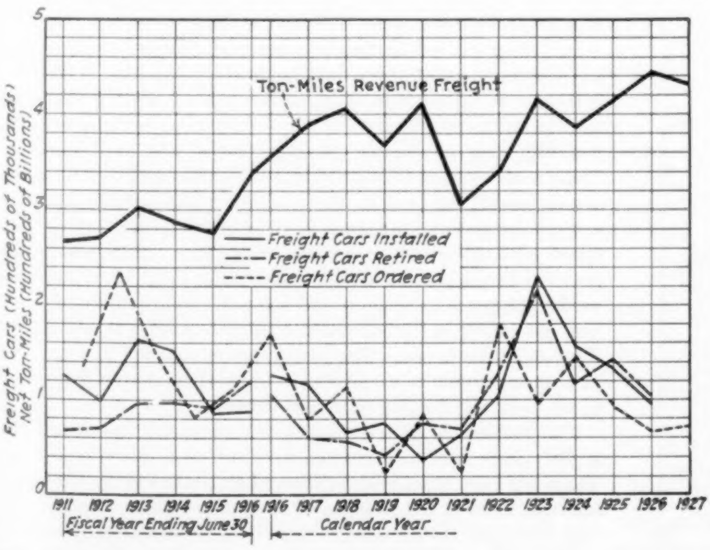


FIG. 8 FREIGHT CARS ORDERED, INSTALLED AND RETIRED ANNUALLY SINCE 1911

Before leaving cars, it may perhaps be well to bring together in a brief summary the salient features of the situation. The car ownership of the Class I railroads has shown little tendency either to increase or decline since 1920. It has been supplemented by a slightly increasing proportion of cars of private ownership, mostly of special types such as refrigerator and tank cars. The physical condition of the equipment has steadily improved, large numbers of cars having been rebuilt with betterments by the carriers, notably in 1923. With each succeeding increase in business, this fairly constant number of cars has rendered a slightly increasing amount of service, but the promptness of the service has increased very materially. More car loadings

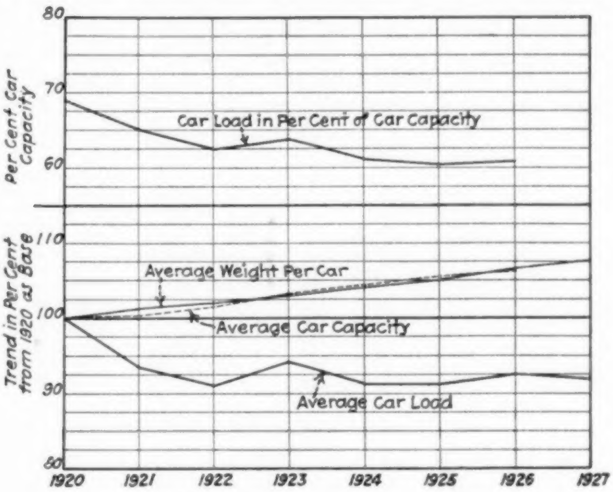


FIG. 9 CAR LOADING IN RELATION TO CAR CAPACITY

TABLE 3 FREIGHT LOCOMOTIVES

| Year | On line | Stored | Per cent unserviceable | Active locomotives | Average tractive force, lb. |
|---|---|---|---|---|---|
| 1920 | 30,081 | 669 | 24.3 | 22,102 | .... |
| 1921 | 32,891 | 3,939 | 24.0 | 21,158 | .... |
| 1922 | 32,859 | 2,932 | 25.5 | 21,552 | 42,452 |
| 1923 | 32,976 | 1,481 | 21.6 | 24,380 | 43,706 |
| 1924 | 33,230 | 3,827 | 18.8 | 23,153 | 45,300 |
| 1925 | 32,450 | 3,712 | 17.8 | 22,968 | 45,840 |
| 1926 | 31,639 | 2,775 | 16.4 | 23,679 | 46,750 |
| 1927 (11 months) | 30,570 | 4,707 | 16.1 | 20,943 | 48,000 |

have been required because of the decline in the average load. This improved service has been effected at the expense of a marked increase in empty car-miles. This increase in the proportion in 1926 over that in 1920 required the operation of approximately 3.5 per cent more freight train miles and, in 1927, approximately 4.4 per cent more train miles than would have been necessary had the 1920 ratio of empty to loaded car-miles prevailed in those years. The aggregate cost of this extra car mileage was about $100,000,000 in 1926 and $120,000,000 in 1927. The average freight-car capacity and weight continue to increase steadily, while the average car load has declined since 1920. There is little reason to expect it again to increase and the very efficiency with which the carriers are serving the public suggests the possibility of a further decline, from reductions in size and increases in the frequency of merchandise shipments.

Shall this condition continue unchecked? May it not be possible that some of the increased empty car mileage could be traded at a profit for more cars? May it not be time for car designers to study the problems of weight and capacity, particularly of box cars, in the light of changing conditions?

### LOCOMOTIVE UTILIZATION

What has happened in the use of locomotives since 1920 is fully as remarkable as what took place with respect to freight cars. Fig. 10 shows the number of locomotives, both in freight and passenger service, with which the railroads have handled their business. There was an average of 30,081 freight loco-

motives on the lines of the Class I railroads in 1920. The number increased slightly following 1920, declining again to 30,570 during 1927. Since 1922 there has been a steady decline in the percentage of unserviceable locomotives, the effect of which on the total number of serviceable locomotives is indicated by the second line from the top of the graph. There has been considerable fluctuation in the number of freight locomotives stored serviceable since 1920, the number decreasing in the years of heavy business like 1923 and 1926. By deducting the stored

TABLE 4 FREIGHT-TRAIN PERFORMANCE

| Year | Train miles (000) | Locomotive miles (000) | Train load Gross | Train load Net | Average miles per hr. | Gross ton-miles per train-hr. | Average miles per day, all locos. | Average miles per year, active locos. |
|---|---|---|---|---|---|---|---|---|
| 1920 | 634,201 | 718,605 | 1443 | 708 | 10.3 | 14,890 | 65.3 | 32,500 |
| 1921 | 529,177 | 593,552 | 1435 | 651 | 11.5 | 16,550 | 49.4 | 28,000 |
| 1922 | 554,780 | 623,885 | 1466 | 677 | 11.1 | 16,220 | 52.0 | 29,000 |
| 1923 | 641,556 | 725,663 | 1539 | 713 | 10.9 | 16,790 | 60.3 | 29,800 |
| 1924 | 600,576 | 673,289 | 1588 | 715 | 11.5 | 18,257 | 54.5 | 29,100 |
| 1925 | 612,865 | 689,797 | 1670 | 744 | 11.8 | 19,679 | 58.2 | 30,000 |
| 1926 | 632,557 | 713,875 | 1737 | 772 | 11.9 | 20,705 | 61.8 | 30,100 |
| 1927 | 610,497 | 689,177 | 1780 | 778 | 12.3 | 21,945 | .. | 33,000 |

TABLE 5 PASSENGER LOCOMOTIVES

| Year | On line | Stored | Per cent unserviceable | Active locomotives | Average tractive force, lb. |
|---|---|---|---|---|---|
| 1920 | 13,684 | .. | 24.8 | ... | ... |
| 1921 | 15,039 | 599 | 23.1 | 10,970 | ... |
| 1922 | 14,944 | 540 | 23.5 | 10,889 | 26,745 |
| 1923 | 14,547 | 331 | 20.8 | 11,191 | 27,456 |
| 1924 | 14,544 | 776 | 18.5 | 11,078 | 28,200 |
| 1925 | 14,372 | 906 | 17.9 | 10,896 | 29,000 |
| 1926 | 13,876 | 991 | 17.0 | 10,525 | 29,800 |
| 1927 (11 months) | 13,526 | 1106 | 16.5 | 10,190 | 30,800 |

locomotives from the serviceable, the freight locomotives which may be considered as being in active service are shown by the third line in the graph.

How has this locomotive supply been used? There was a

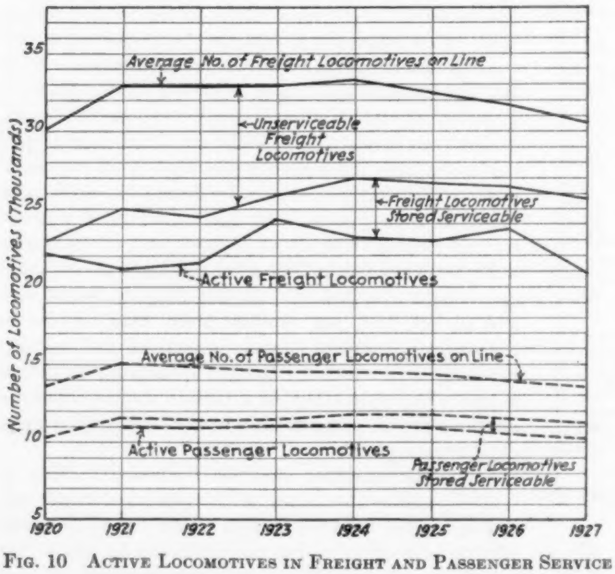


Fig. 10 Active Locomotives in Freight and Passenger Service

decline in the intensity of the use of the active locomotives following 1920 which is indicated by the average miles per year which these locomotives made. Starting with 32,500 in 1920, the average freight-locomotive mileage dropped to 28,000 in 1921, and with the exception of a slight decline in 1924, it increased steadily but slowly until it reached 30,100 during the peak year of 1926. What is most striking is the fact that with the decline in business in 1927, the actual use of the active locomotives has shown a marked increase to an average mileage of 33,000. This is illustrated in Fig. 11.

Beginning with 1922, for which the figures are first readily available, the average tractive force of locomotives in freight service was 42,452 lb. This increased steadily until in 1927 it had reached 48,000 lb. During the same period the gross train load had increased from 1466 tons to 1780 tons. In Fig. 12 it will be seen that this increase in train load was considerably greater than the increase in the average tractive force of the locomotives, indicating a better average utilization of the potential tractive capacity. This improvement, in the face of the increase in average train speed from 11.1 miles per hour in 1922 to 12.3 miles per hour in 1927, indicates a splendid performance. The combined effect of this increase in train load and train

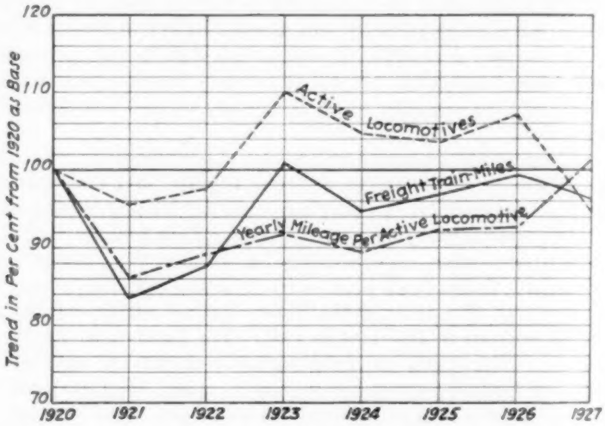


Fig. 11 Trend in Yearly Mileage per Active Freight Locomotive

speed is indicated by the gross ton-miles per train-hour which were 35 per cent greater in 1927 than in 1922.

So far as the locomotive is concerned, this is a reflection of the tendency toward increased horsepower capacity in modern locomotives. Attention must, however, be called to the fact that locomotive utilization is affected by the character of other facilities such as signals, passing tracks, and yard facilities. There was a period following the termination of Federal control during which the lack of these facilities in adequate quantity exercised a material influence in keeping down the average train speed and materially increasing train-hours. Long delays on poorly located passing tracks and equally long delays awaiting yard track space in which to put away the train at the end of the run, not infrequently consumed from one-quarter to one-half of the total train-hours. The performance reflected in Fig. 12 is in part the result of a constantly improving coordination of all of the facilities affecting train movement.

The number of active passenger locomotives has varied but slightly since 1921, as is indicated by the lower curves on Fig. 10. There has been a decrease in ownership, a decrease in unserviceable locomotives, but an increase in the margin stored serviceable. The variation in the relationship of passenger train-miles, the number of active locomotives, and the yearly average miles per active passenger locomotive has been much less than the variations in the similar relationships for freight locomotives. It is, however, interesting to note on Fig. 13 that since 1921 there has been a steady, although not large, increase in the miles per active locomotive per year until 1925, and a much greater increase in 1926.

It is in passenger-train service that the most effective results are obtainable from long locomotive runs. The movement toward increasing passenger-locomotive runs has been progressing

steadily for several years and has undoubtedly been the major influence in producing this increase.

It was possible to show clearly the relation between the increase in the average tractive force of the locomotives and the gross tons per train in freight service. The data are not available from which to show this relationship with equal clearness in the case of passenger locomotives. There has been a steady increase in the average tractive force of passenger locomotives just as there has been in the case of freight locomotives. In 1922 the average was 26,745 and in 1927 it had reached 30,800 lb. The average passenger train in 1922 consisted of 6.4 cars and had increased to 7 cars in 1927. How this increase in the train length compares with the increase in the tractive force of the locomotives is indicated in Fig. 14.

The average length of the passenger train, however, does not

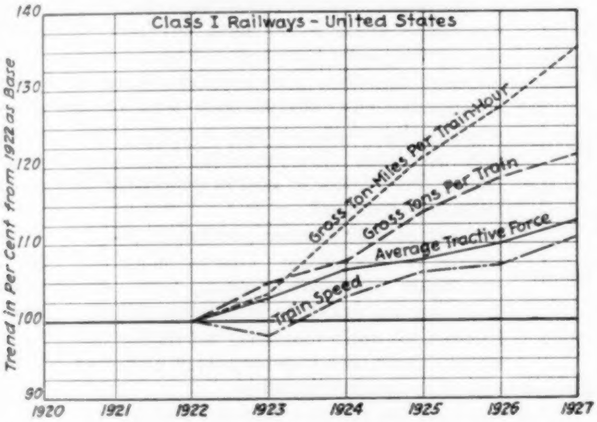


Fig. 12 The Relation of Train Load to Tractive Capacity and the Trend of Ton-Miles per Train-Hour

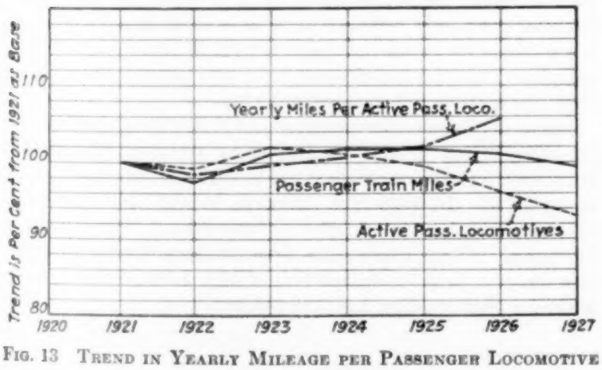


Fig. 13 Trend in Yearly Mileage per Passenger Locomotive

tell the whole story. In 1922, of the 6.4 cars per train, an average slightly less than 2.0, probably about 1.8, were sleeping, parlor, or dining cars. Probably about 2.5 cars of the 7-car train in 1927 were of this heavy type of equipment. Furthermore, there has been a steady increase in the number of steel and steel underframe coaches, baggage, and express cars, with a corresponding decrease in the number of wood cars. The total number of passenger cars of railroad ownership in service has not changed materially from between 54,000 and 55,000, but at the beginning of 1923, 24,000 of these cars were of steel or steel underframe construction and, in 1927, some 34,000 were of steel or steel underframe construction.

How far this increasing weight of the average car of railroad ownership and the increasing number of Pullman cars in the train has tended to increase the weight of the train above that indicated by increase in length, it would be very difficult to say.

TABLE 6 PASSENGER-TRAIN PERFORMANCE

| Year | Train miles (000) | Locomotive miles (000) | Average cars per train | Average miles per day, all locomotives | Average miles per year, active locomotives |
|---|---|---|---|---|---|
| 1920 | 555,201 | 583,774 | 6.4 | ... | .... |
| 1921 | 543,808 | 567,848 | 6.4 | ... | 51,800 |
| 1922 | 530,197 | 554,953 | 6.4 | ... | 51,000 |
| 1923 | 549,841 | 577,101 | 6.5 | ... | 51,600 |
| 1924 | 553,253 | 577,876 | 6.6 | 108.6 | 52,200 |
| 1925 | 553,344 | 578,525 | 6.7 | 110.3 | 53,000 |
| 1926 | 550,386 | 576,441 | 6.9 | 113.8 | 54,800 |
| 1927 | 539,297 | ..... | 7.0 | 114.4 | .... |

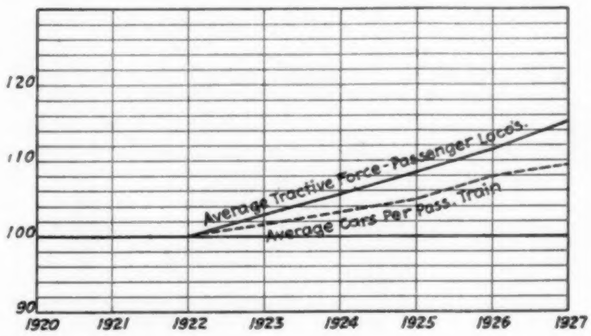


Fig. 14 Trend in Passenger-Locomotive Tractive Force and Train Lengths

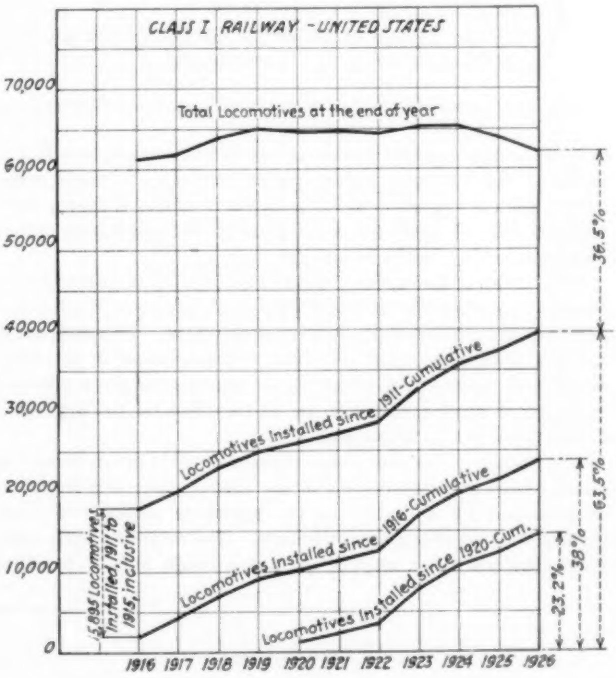


Fig. 15 Locomotives Installed Since 1911

## Locomotive Conditions

In the discussion of cars, an attempt was made to show what the railroads have done in keeping up the quality of the cars in service. Much the same information is available for locomotives. Fig. 15 has been prepared to give some idea of the age of the locomotives now in service. It will be seen that of the 62,400 locomotives in service at the end of 1926, 63.5 per cent were installed since 1911. In other words, approximately 64 per cent of the power in service at the end of 1916 was then 16 years old or less. Of these locomotives, 23,700, or approximately 38 per cent of the total locomotives in service, had been installed since 1916 and were 10 years old, or less, and 14,700 or approximately

25 per cent of the total number of locomotives, had been installed since 1920 and were not over 7 years old.

Here the term "installed" implies the same thing as it did in the case of cars and if one follows the curves on Fig. 16, it will be evident that many locomotives which were installed in 1923 were old locomotives which were rebuilt either in the shops of the roads

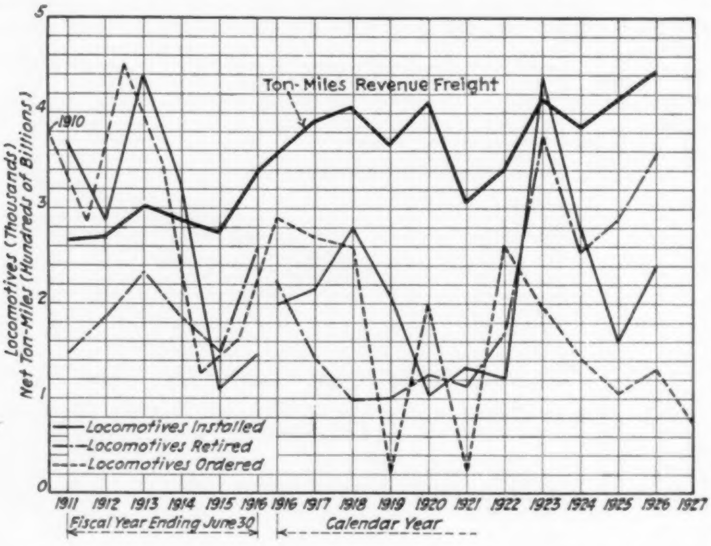


Fig. 16 Locomotives Ordered, Installed, and Retired Since 1911

or in contract shops and accounted for as new locomotives in the books of the carriers. These locomotives were in most cases rebuilt with betterments and, though not wholly modern, they are probably all equipped with some of the appliances which characterize the modern locomotive.

An interesting fact brought out in Fig. 16 is the large number of locomotives retired in 1925 and 1926, with relatively small numbers of locomotives installed during those years. This suggests a marked clean-up of obsolete power. The decrease in the total number of locomotives which these retirements have effected has been of small moment so far as its effect on the aggregate locomotive capacity is concerned.

The decline in the percentage of unserviceable locomotives has already been mentioned. As in the case of cars, this has been accompanied by a decline in the aggregate amount of labor expended in locomotive maintenance. The monthly hours paid for machinists' labor may be used as a rough index. Starting with about 12 million in the fall of 1921, there was a heavy reduction during the strike to a low point of about $4^{1}/_{3}$ million. By January, 1923, a high point of almost 16 million was reached. There was a decline to 12 million by the middle of 1924. Following a rise to $13^{1}/_{3}$ million at the end of the year, there have been no further sharp changes, the average remaining between 12 and 13 million throughout 1925 and 1926. The average during 1927 has been slightly under 12 million, in keeping with the decline in the business handled last year.

The essential facts pertaining to the locomotive situation may be summarized as follows: There has been a relatively small change in the number of locomotives in service since 1920. Increases in the number of locomotives during the first years of this period have been offset by decreases during the past three years. No immediate shortage of power is indicated, however. The condition of the power has improved and, owing to more intensive use, there is an increased reserve of serviceable locomotives. Freight train-miles continue to decrease owing to the increase in unit tractive capacity and train load. The increasing train speed has decreased train-hours in greater proportion than train-miles have decreased.

There is still another problem of utilization with respect to locomotives. That is, taking advantage of the highly developed traveling power plants which have become available within the past five years—locomotives which materially exceed the capacity possible to obtain within the range of proportions commonly adhered to no more than five years ago.

When one considers that the splendid performance, particularly in freight-train service with its reduced train-hours and greatly improved fuel economy of the past three years, must have been in great degree the result of the better coordination of facilities previously referred to, it is evident that there is still a big future for continued improvement in these respects when completely modern locomotives come into use in sufficient numbers to make their influence generally felt.

Major dependence for improvement in operating economy was for many years placed on increasing tractive capacity and train load. Each train-mile saved in this way, at present, saves about \$1.50. In 1926 each overtime freight train-hour saved by the Class I railways effected an average saving of \$9.10 for wages. At their face value these facts would seem to emphasize the rich field for locomotives of high horsepower capacity, wherever crew overtime has to be paid for.

## Discussion

William Elmer.[2] As the representative of the motive-power department, it has been the duty of the writer to prepare engines and cars for service on the road. It has been a gratification to many of the railroad men who, perhaps, looked farther ahead, to see their ideas at last come to fruition.

A new engine house was built at Altoona a few years ago, and many labor- and time-saving devices were installed. The writer's opinion is that not all of those features were appreciated at the time, but as the years went by, those devices to quicken operation became of the utmost importance. Looking back on the records that were made, and recalling the fact that 400 engines were handled each day at that one terminal, it is gratifying to know that the railroads have been able to keep up their end in this procession of progress and to help make the figures which the author has presented. He has painted an excellent bird's-eye view of the work that has been done in the last few years, and he is to be congratulated on the manner in which he has picked out those things which have produced this remarkable showing by the railroads.

The details, of course, he could not handle in a general survey such as he made. These are taken from the usual statistics which are accessible to all railroaders and the public in general if they care to look them up. Some of the developments that made those figures possible are intensely interesting.

Intensive effort from the highest to the lowest officer is required to obtain the performances which have made possible the figures which the author has given. Railroad officers who have either heard or read this paper must realize that it is their duty to continue these splendid performances and improve upon them.

[2] Special Engineer, Pennsylvania Railroad Co., Philadelphia, Pa. Mem. A.S.M.E.

Roy V. Wright.[3] We can learn a great lesson, as engineers, by studying the causes of the remarkable records mentioned by the author. A railroad officer in a recent discussion of operating conditions on a 110-mile division stated that not many years ago freight-train crews carried most wonderful dinner pails—pails costing several dollars each and large enough to carry three or four meals. Today these men carry no dinner pails. They eat before leaving home, and they get their next meal at the other end of the run, since it is regularly made in four and a half or five hours. Formerly trains were tied up on this division because of the "hog law"—the 16-hour law. Today this law has been forgotten on this particular division. Why?

If we study operating conditions of a few years ago, we find that there were a great many things that caused delays. For one thing, departmental lines were too strongly drawn. Then, too, the executives did not realize the necessity of giving the mechanical department greater responsibility and support, in order that the equipment could be kept in the best of condition at all times.

In 1922, when the railroads were becoming desperate with continued congestion, the American Railway Association wisely set up certain goals toward which to strive. As a result, all of the railroads got into a big game and less thought was given to departmental lines. Railroad men as a whole got the idea that they were working not so much for their particular department as for a great organization, whose duty it was to get freight and passengers over the road; they went into it in a spirit of play, as if it were a great game.

When the ball is started in motion in a football game, ten men on the team devote their efforts to clearing the way for the man carrying the ball, in the effort to prevent his being interfered with. Today, when an engineman is given an engine with a train behind it, every one gets busy in doing his part to prevent the train from being stopped, in order that it may get over the road as quickly as possible. Then, too, tremendous amounts of money have been expended to provide double or multiple tracks, longer sidings, better locomotives and equipment, improved signals, and car retarders in freight-train yards. Main-track trains are frequently run 1000 miles or more without being broken up at division points as in former days. As Secretary of Commerce Hoover stated a year ago, the shipper and the receiver of freight can depend upon material's being delivered on schedule time. This has been a great factor in stabilizing business.

[3] Editor, *Railway Mechanical Engineer*, New York, N. Y. Mem. A.S.M.E.

# Car Retarders, a Recent Development in Railway-Yard Operation

By L. Richardson,[1] Boston, Mass.

One of the important operations in railway transportation is the sorting or classifying of cars at division or terminal yards. During the past 25 years the so-called hump yard has been generally conceded to be most economical means of classifying cars. The hump yard has one or two tracks on an ascending grade to a summit, over which a train of cars is pushed by a humping engine, usually at a speed of two to four miles per hour. The cars are uncoupled or "cut" by the conductor of the humping crew just before reaching the summit, and then run by gravity down the far side of the hump into the proper classification track. On gravity humps car riders or brakemen control the speed of the cars down the hump and ladders to prevent them from running into other cars standing on a classification track at a speed that might damage cars and lading. Two miles per hour for loads, and a corresponding higher rate for empties, is considered as a safe coupling speed. The riders climb on the cars before reaching the hump, one to each car or group of cars, known as a cut, try the brakes to see that they are operating properly, ride the car until it reaches its classification track, and after checking the speed of the car to about 3 miles an hour either walk back to the hump or are carried there by a motor car on a special track. A considerable part of the car rider's time is therefore spent in returning to the hump, and unless traffic is fairly uniform he also spends much time waiting for trains to be humped. Obviously the capacity of a yard depends upon the number of riders available. Where traffic is uniform it is not difficult to provide a suitable number of riders, but where traffic varies greatly, as is the case in most yards, it would not be economical to provide a sufficient number of riders to handle peak periods promptly. During such periods it is necessary to wait for riders, while at other times the riders are idle.

The number of cars that can be handled by a rider in a day, or an 8-hour trick, varies considerably, depending on the length of the classification tracks, on whether he walks or rides back, and on the average number of cars per cut. From 25 to 50 cars per rider is the usual practice. A car rider's wages are about $7 for an 8-hour trick.

Ordinarily track switches are thrown by switch tenders, the number depending on traffic. In some yards the switches are power-operated and are controlled from a lever machine at or near the hump. The number of 8-hour tricks worked per day, as well as the number of engine crews on each trick, also depends upon traffic.

### Usual Arrangement of Car-Rider Yard

The usual hump yard has one or two tracks from the hump and one or more ladder tracks, along which at regular intervals are the classification-track switches. This arrangement is essential with hand-operated switches so that the switch tenders can walk or run along the ladder tracks and seldom have to cross tracks.

Grades vary greatly, but it is usual to have a short stretch of 3 or 4 per cent just below the hump and then 1 per cent extending some distance into the yard. In certain cases the 1 per cent grade begins at the hump and extends nearly to the end of the yard.

The height of a hump can be computed approximately, and then raised or lowered until it is suitable for the requirements of the yard and for the character of the traffic handled. In general a higher hump is required for empty cars than for loads, and also for winter conditions as compared with summer ones. In some yards the height of the hump is increased a foot or two before winter begins, and lowered the same distance in the spring. In other yards two humps are provided, a high one for winter and a low one for summer.

The disadvantages of car-rider operation are as follows:

- Unsuitability for sudden peak demands.
- Cost of riders, switch tenders, and other employees.
- Personal injuries to employees.
- Damage to cars and lading.
- Pilferage of cars by riders and other employees at night.
- Cleaning yard of coal, etc., falling from cars.

### Development of the Retarder

In order to reduce the cost and to eliminate the hazard of hump operation, experimental tests were conducted by President Hannauer of the Boston & Maine (then vice-president of the Indiana Harbor Belt) and his associates at their Michigan Avenue car shop with a device for the retardation of cars moving on tracks.

The principles developed here were then applied in a retarder placed on the west-bound Gibson hump on September 15, 1923, consisting of two 40-ft. sections at the foot of the incline of the hump. These machines were first operated by four-way air valves from a central point, they being placed in a small building at the foot of the hump, and later by electropneumatic valves. The latter displaced the hand throw and simplified the work of the retarder operators, making it possible for them to handle the cars with greater rapidity.

The first tests were successful, but the question then came up as to the action during extreme cold weather, especially when accompanied by snow. These tests were continued later in 1923, during cold weather and snowstorms, and as no adverse effect was noted in the operation, this led to further installations early in 1924. Operation was then continued with four retarders, other units being added, until in December, 1924, the west-bound yard was completely equipped.

The first retarders were constructed from convenient railway materials, such as car springs and brake cylinders. Refinements in design have progressed to the point where practically every member has been designed for the required service and manufactured accordingly.

The car retarder (Fig. 1) is a track brake which presses against both sides of the lower part of the car wheels in the same manner as a vise, the pressure being controlled by an operator according to the weight and the speed of the car—heavy retardation for a heavy load and little or no retardation for an empty. There are two types of car-retarder systems in service on the railways of the United States—the all-electric system, in which retarders, switch machines, and skate machines are controlled and operated by electric energy, and the electropneumatic system, in which similar units are controlled by electric energy and operated by compressed air.

[1] Mechanical Superintendent, Boston & Maine R.R.

Contributed by the Railroad Division and presented at the New England Industries Meeting, Boston, Mass., October 1 to 3, 1928, of The American Society of Mechanical Engineers.

## Details of Retarder Construction

The shoe beams are of special alloy steel, 5 ft. 6 in. long, articulated to prevent binding due to variation in the grade of the track. The top of the brake shoe is 2 in. above the top of the rail. The wheel space is 7 in. open and 4 in. closed. Every third tie is a steel I-beam. Car retarders are ordinarily 33 ft. to 40 ft. long. The latter is the maximum length operated by one mechanism; if greater lengths are required, two or more units are used. The weight of a 33-ft. retarder and mechanism is approximately 16 tons and of a 38-ft. 6-in. retarder approximately $18^1/_2$ tons. The construction of a retarder is

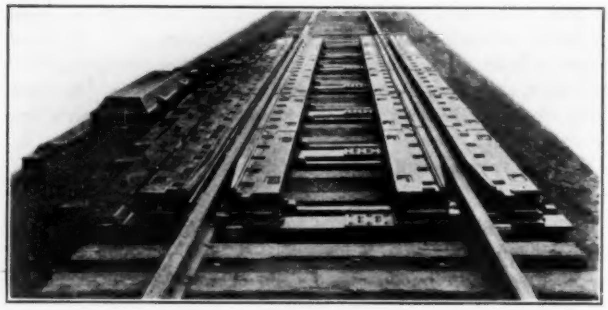

Fig. 1 Heavy-Duty All-Electric Car Retarder

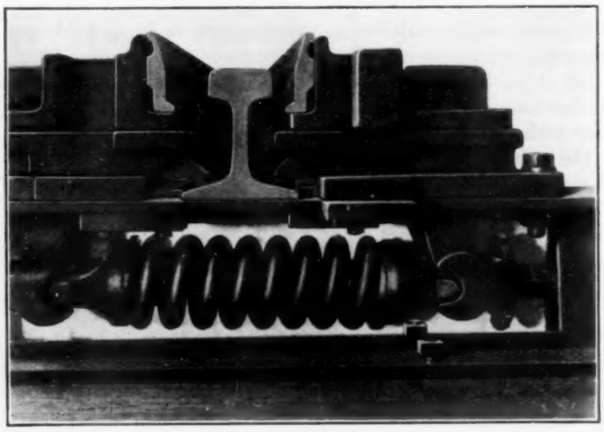

Fig. 2 End View of Retarder, Showing Heavy Springs

such that there is little chance of any dragging car equipment's fouling the retarder, and also a derailed car could do little damage owing to the heavy and substantial parts, capable of bearing the weight of a car or a locomotive. The cranks are mounted in heavy longitudinal members bolted to the ties. The long arm of the crank is attached to a longitudinal operating bar, which is connected to the mechanism. The short arm of the crank is connected to cross-members which operate the spring mechanism under each rail. There are 12 sets of springs for the 33-ft. retarder and 14 sets for the 38-ft. 6-in. retarder. Each set has two springs, making a total of 24 and 28 springs, respectively. Fig. 2 is an end view of a retarder member, showing the heavy springs, and Fig. 3 shows a complete electropneumatic retarder.

All forces are self-contained in the mechanism. Under extreme conditions the maximum stress in the members is not over 30,000 lb. per sq. in. and under normal conditions about 15,000 lb. Wood ties are 8 × 12 in., usually of creosoted oak; similar ties 4 × 10 in. provide a good bearing for the steel ties.

In an all-electric retarder the mechanism case is bolted to a longitudinal angle and two ties near the middle of the retarder. It houses a 230-volt 5-hp. motor with suitable gear reduction, a powerful brake that holds the motor stationary and is released only when power is applied to the motor, and a master circuit controller consisting of five sets of contacts, or one set for each position of the lever in the control machine. Control circuits are 115-volt and operating circuits 230-volt. For simplicity and for economy in wire the operating circuits are local, and the master circuit controller in the mechanism controls heavy-duty forward and reverse contactors in a separate housing at the main power line, usually within 50 or 60 ft. of the retarder. In connection with the heavy-duty contactors there is a time element device that opens the operating circuits in case of excessive current if the motor stalls, thus preventing injury to the motor. A fused knife switch is provided to cut off power during inspection or maintenance. The plan of an all-electric retarder is shown in Fig. 4.

The mechanism is attached to the longitudinal operating bar by means of a toggle arrangement, as shown in Fig. 5, which produces a fast movement when the retarder begins to close and a slower movement with enormous pressure near the closed position. The fast movement near the open position affords a quick release. The diagram also shows the spring mechanism and connections which afford equalization of shoe pressure and compensate for variations in the width of the wheels and of the track gage. This feature largely eliminates the possibility of lifting light cars through the application of heavy pressure. Should by any chance a car be lifted, the inner shoes serve as guard rails, and the car would drop back on the rails on clearing the retarder.

In the electropneumatic type the air-operating cylinder is mounted parallel to the track. The air pressure is controlled by electrically operated valves and is transmitted by a "live-lever, dead-lever" arrangement similar to the foundation brake gear

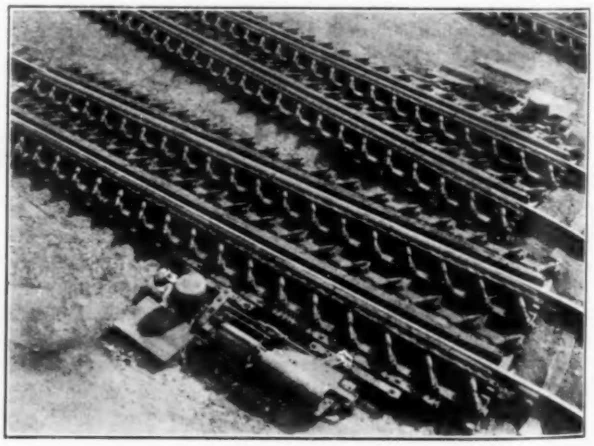

Fig. 3 Electropneumatic Retarder

of a freight car, through bell cranks and springs to the retarder shoe. The pressure is graduated in four steps, and release is accomplished pneumatically, requiring only half the amount of air needed for application, owing to the trunk-piston construction used. Working pressures run as high as 80 to 110 lb. per sq. in.

To take care of wheel-dimension variations very heavy springs are used in the final transmittal of pressure to the shoes. Ample margin is provided so there is no danger of their breaking when subjected to heavy-duty service.

The general practice in handling cars is to set the proper degree of retardation in each retarder before the car reaches it.

as this requires much less current, and also causes less wear on the parts. In some emergencies it is necessary to close a retarder with a car passing through it, usually where proper retardation has not been given in preceding retarders, but this should be avoided if possible.

### Control Machine

The control machine (Fig. 6) consists of a compact steel cabinet with a sloping top divided into panels, which can be raised for inspection of the apparatus. On each panel there is provision for retarder levers, switch levers, skate switches, lever lights, and the name plates for the levers. Each machine has levers for the particular requirements of track layout and retarders. The lever lights, when illuminated, show the operator that the retarder has operated to the corresponding position of the retarder lever. The retarder lever in the all-electric machines has six positions; power off, retarder open, and four degrees of retardation, all of these positions being numbered. The electropneumatic machines have as high as five degrees of retardation, those in Boston having four. The machine and operator are shown in Fig. 7.

Small lights, usually placed just above the switch lever, indicate the normal and reverse positions of the track switches. Where track circuits are used, there is a light for each one which indicates whether a car is on the circuit. With track circuits it is impossible to throw a switch under a car. Ordinarily the retarders are operated to the proper position before a car reaches them, strong retardation for a heavy car and little or none for an empty, as this requires much less current than when a retarder is closed with the wheels of a car therein. In the lower part of the cabinet is a terminal board with panels on which are mounted the main switches, bus bars, fuses, and terminals.

There is usually one lever machine in each control tower, but where two operators work during peak hours, two lever machines of half the size are provided. In most yards two or three control towers are adequate. The determining factor is the number of retarders, switches, and skates that one operator can efficiently handle. The towers should afford a clear view in all directions of that part of the yard controlled from each, so that the operator may observe the speed of the cars and their relative positions. One tower is some distance below the hump and one or more towers are beyond, on one or on both sides of the yard.

### Power Equipment

The power equipment varies according to the commercial current available and the specifications of a particular railroad, but a typical installation is as follows: Two 25-kw., one 3-kw., and one 1-kw. a.c.-d.c. motor-generator sets, one 240-volt 160-amp. storage battery, and switchboards with control apparatus, switches, meters, etc. Power for operation of the retarder system is furnished by the 25-kw. motor-generators, which are usually operated on 440 or 550 volts a.c. and which deliver 230 volts d.c. Two are installed, one being in regular use while the other serves as an emergency unit. The 1-kw. set is used for trickle-charging the storage battery, and the 3-kw. set to charge at a higher rate when necessary, it being possible to charge by both sets connected in multiple. In case of failure of the commercial current the load is automatically switched to the storage battery, which latter will operate the plant for some time.

The power plant for the electropneumatic type is more simple, consisting of compressors, usually motor-driven, and 6-volt battery circuits for the control. The air capacity is not determined by the number of retarders, but by the number of switch and retarder movements. The power equipment is housed in a small building near the center of the load or in a lower story of one of the towers. Motor-generators, compressors, and switchboards are placed in one room and the storage battery in a separate room so as to avoid injurious effects from the sulphuric-acid fumes.

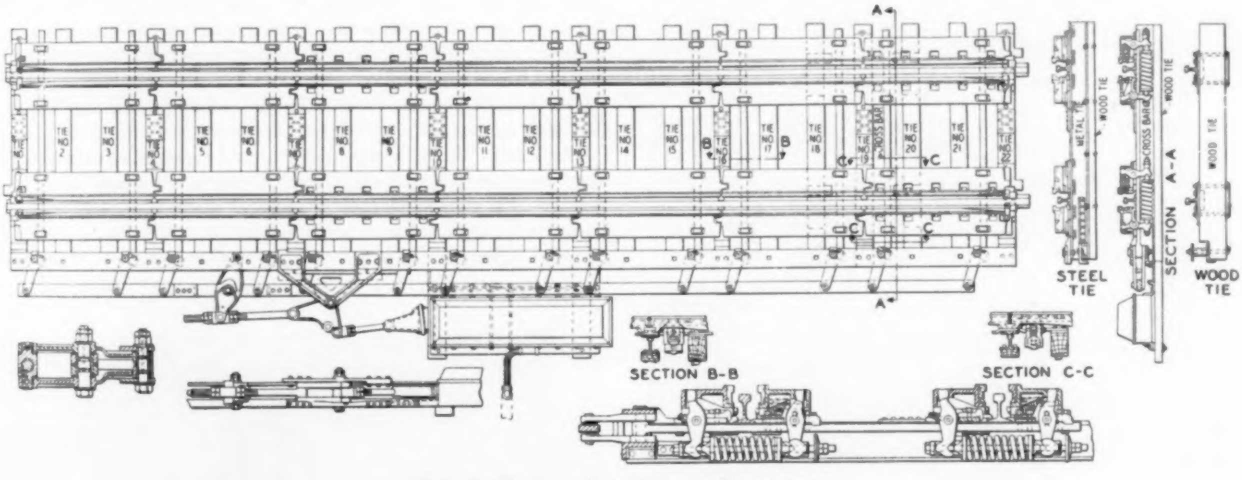


Fig. 4 Plan of All-Electric Retarder

The power required varies with the number of cars handled and other conditions. Figures obtained from one of the first retarder installations show approximately 0.04 kw-hr. per car. Assuming that 1000 cars are handled per day and that current costs $0.03 per kw-hr., the monthly cost of power would be approximately $37.20.

### Switch-Operating Mechanisms

The switch machines which operate the track switches are similar to the switch machines used in electric interlocking, the difference being that some of the protective features not required for low-speed yard operation have been eliminated. Each switch is operated from normal to reverse position or vice versa from a two-position lever in the control machine. The operating time is about one second, which is well under any requirements. The position of the switch is indicated by two lights on the control machine, one light indicating normal position and the other the reverse position. The switch machine follows instantly the position of its control lever. The switch machines are either electropneumatic or all-electric.

The latter operate on 115 volts, one side of the circuit being connected to the 230-volt power line and the other to the neutral wire. A two-indication color-light signal is usually installed at each switch, as shown in Fig. 8, which not only indicates the position of the switch, but serves as a location marker, which is of considerable assistance to the operator at night in spacing cars from the hump. It is the practice of some railroads to install detector track circuits at each switch to prevent the throwing of a switch under a train, essentially the same as in interlocking practice. However, this has a tendency to slow up operation. With well-drilled operators it is not felt that this protection is warranted.

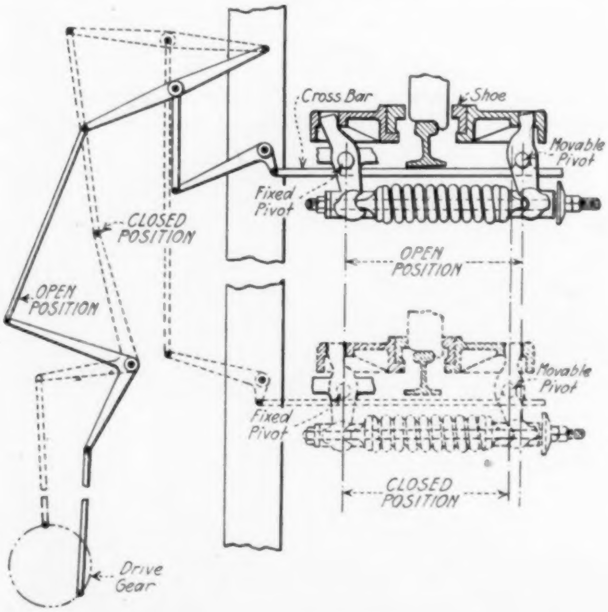


Fig. 5 Diagram Showing Quick-Closing Principle

### Skate and Skate Machine

The skate (Fig. 9), although solely a safety feature, is used on a number of retarder installations, being placed on each track just beyond the frog at the clearance point. The skate is used only in the emergency of a car leaving the last retarder at too high a speed, which might result from improper handling by one or more operators, or in the case where a loaded car was improperly designated as an empty on the operator's list. The skate consists of a steel casting with its upper surface curved, the base of the skate fitting into a supporting frame which is connected to a simple mechanism in such a manner that the skate is raised from its normal horizontal position beside the rail to a vertical position on the rail. The skate machine operates similarly to the switch machine and is controlled by means of a switch on the control machine.

### Humping Trimmer Signals

Engine movements in the yard are controlled by two or more color-light signals, each of which indicates in both directions. One signal at or near the crest of the hump is controlled by the hump engine conductor, who cuts off the cars as they are pushed up the hump grade; the other signals repeat the indications of the hump signal and are located along the hump lead so that an indication is always visible ahead of the humping engine regardless of the length of the train. The aspects and indications vary among the railroads, but the following are typical:

*Signals Facing North or West*

| Color | Indication |
|---|---|
| Red | Stop |
| Yellow | Proceed at normal humping speed |
| Two yellow | Proceed at fast humping speed |
| Green | Proceed at normal yard speed |
| Yellow over red | Back up. |

*Signals Facing South or East*

| Color | Indication |
|---|---|
| Red | Engines in classification yard remain in clear; humping is proceeding |
| Green | Humping has ceased; engines in classification yard may come out on lead. |

The first set of indications governs humping operations and the second set trimming or similar operations. In yard parlance the term "trimming" refers to the pushing into the clear of cars that may foul other tracks, also to pushing cars to the far end of the classification tracks so as to make room for additional cars. In some yards the necessary trimming is done by the humping engine after it has humped a train, and in other yards by another engine known as the trimmer engine, which stands by during humping operations.

The control of the humping signal and repeater signals is such that the operator in the first tower can at all times cause the display of a stop indication in cases of emergency, and in such cases the hump conductor must put his control lever to the stop position before he can give proceed indications. For the information of the operator the indications of the hump signal are repeated in the first tower.

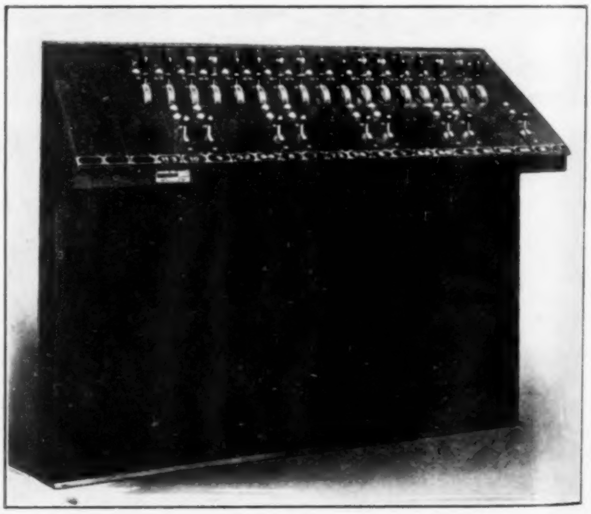

Fig. 6 Control for Retarders, Switches, and Skates

### Wire and Wiring Circuits

The control and operating wires in some cases are placed in wood or concrete trunking supported on wood or concrete stakes, and in other cases they are in the form of cable buried in the ground. The advantage of the trunking arrangement is that the full length of all wires is easily available for inspection in case of trouble. The chief advantage of the cable is that it is out of sight below ground and is not subject to damage by derailments, workmen, etc. There is some question as to which arrangement is the more economical, but both are extensively used.

The wires and cables are usually in accordance with the speci-

fications of the American Railway Association, Signal Section, as car-retarder plants are usually installed by or under the direction of the signal department, as well as being maintained by that department.

### Auxiliary Apparatus

Some of the auxiliary features in a retarder yard, and which are also used in car-rider yards, are as follows:

1 Teletype system, by means of which typewritten lists of cars and their weights are transmitted simultaneously from the yard office to the hump, all towers, and other points where required. Pneumatic tubes are sometimes used for distributing lists.

2 Loud-speaker telephone system, with transmitters and receivers at the hump and each tower, so that the conductor at the hump and the tower operators can communicate with each other easily and quickly.

3 Short-wave radio apparatus for communication between the conductor at the hump and the engineer of the humping engine. A trial of this system has given satisfactory results on one important installation (Selkirk Yard, New York Central), where 125-car trains are humped.

4 Flood lighting, essentially the same as in any hump yard for night operation, but arranged with respect to the view of the retarder operators.

5 Track scales, when required, the same as in any hump yard.

6 Mechanical hump, which provides means for raising or lowering the hump to compensate for the different running of the cars in winter and in summer. With a hump high enough for the worst condition, as an empty car on a cold winter day, and

Fig. 7 Machine and Operator in Tower

with sufficient retarders, a mechanical hump is unnecessary, and one has not been included in a retarder installation since 1926.

7 Hot-oil plants to apply hot oil under pressure to car journals in cold weather to cause the cars, especially the light loads and the empties, to roll freely and so not to delay operations.

### How Retarder System Operates

Retarder, switch machines, and skates are controlled from two or three towers (sometimes four or five towers in very large yards) at suitable places, and the operator in each tower controls all the retarder switches and skates in his section.

When humping operations are not in progress, the jaws of

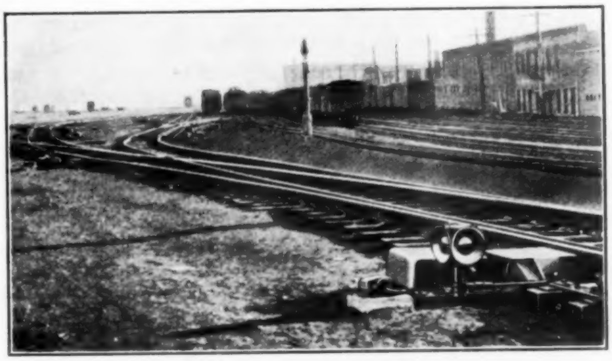

Fig. 8 Electropneumatic Retarders and Switch Machines

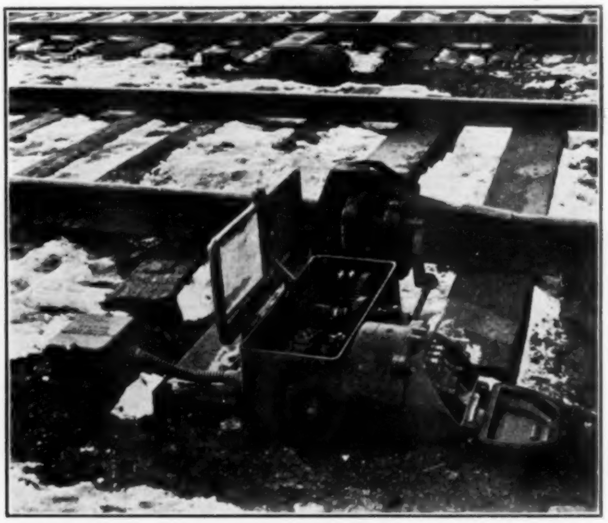

Fig. 9 Skate-Placing Machine

the retarder are open so that engines and cars can pass through them freely. As each cut leaves the hump each operator sets the several switches in position to line up the respective route, and then sets each retarder at one of its four degrees of retardation; in general, heavy retardation for a heavy loaded car and little or no retardation for an empty car. The proper amount of retardation at each retarder depends upon the weight and speed of a car or cut, the necessary spacing to prevent fouling of cars, and the destination of the following cuts. With cars of similar weights a close spacing can be maintained. The most unfavorable condition is a heavy load followed by an empty proceeding to adjacent classification tracks, as it is necessary to apply considerable retardation to the former to prevent acceleration and to allow the empty to proceed with little or no retardation so as not to stop it on the leads and block the yard. Such a case is properly handled by providing a suitable time interval at the hump.

After handling the cars through several retarders they are finally let out of the last retarder at a speed of about 3 miles an hour on a non-accelerating grade, and at which speed they may

bump other cars standing on the same track without damage to cars and lading. The retarder operators quickly become expert in handling the cars under all conditions, and there are records of some remarkable performances where 150 to 200 cars have been humped in an hour.

### Cycle of Operations in Retarder Yard

The operations in a retarder yard vary somewhat according to conditions, but the following are typical:

1 Incoming train arrives at receiving yard.

2 Waybills are delivered to yard office.

3 Inspection of train by yard force; bad-order cars are so indicated and are later switched from the train.

4 Lists showing car numbers, information as to weights (L indicating load, LL for heavy load, E for empty, etc.), and track number or classification to which cars are destined, in the same sequence as the cars stand in the train, are simultaneously transmitted to each retarder operator, to the yard conductor at the hump, and to other points about the yard as required, by means of the teletype machine or pneumatic tubes.

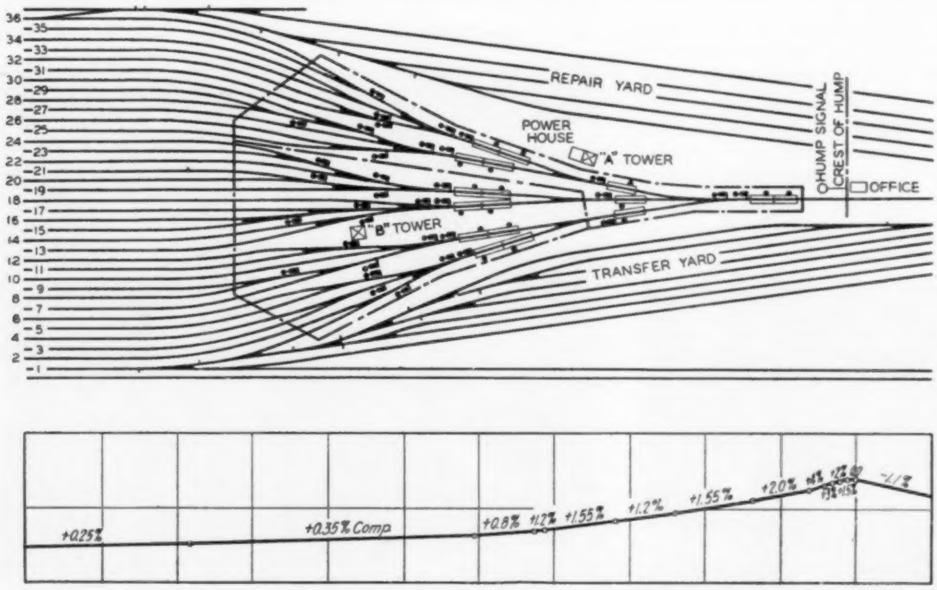


Fig. 10 Track Plan and Profile of Grade of Hump

5 Hump engine is coupled to rear of train, and as soon as humping signal is displayed, pushes the train up the hump.

6 Hump conductor cuts off cars at hump in accordance with teletype list.

7 Retarder operators set switches and retarder in proper position in accordance with teletype list, checking each cut as handled. In cases of emergency the operators also set the skates to stop a car that has left the last retarder at too high speed.

8 Hump conductor gives special information or instructions to operators by means of loud-speaker telephone system.

9 When train is humped, the humping engine and crew do any trimming that is necessary, and then return to receiving yard for another train or engage in other switching operations if there are no trains in receiving yard.

10 Outbound train made up at the far end of classification tracks, leaving from one of the classification tracks or in some cases from a departure yard.

Only part of the time of the humping engine and crew is spent on humping or trimming, the rest of the time being spent in making up trains, delivering transfers, and in miscellaneous switching operations about the yard, in which the retarder operators often serve as part of the crew.

### Operating and Maintenance Force in Retarder Yard

The operating force in a retarder yard comprises one or two engines, each with engineer, fireman, conductor, and two brakemen; a retarder operator in each tower; and the usual yard staff of yardmaster, assistants, clerks, etc., as in any yard of similar traffic conditions.

The maintenance force, under direction of the signal department on account of its being familiar with similar apparatus, usually is made up of a maintainer on each trick during which humping takes place and two helpers on the day trick. The helpers are usually yard section men assigned to the oiling of retarders for a part of their time. The number of maintainers depends upon the size of the plant, traffic conditions, and method of operation, but one maintainer always should be available during humping operations in case something should go wrong.

Maintenance work includes the frequent lubrication of retarders and other mechanism; the replacement of worn retarder shoes, they lasting from several months to a year or more, depending upon their location in the hump, or intermediate, or on classification tracks as well as on the traffic; adjustment to compensate for shoe wear; and the routine inspection and care of the apparatus.

### Arrangement of Tracks and Grades

The maximum capacity of a retarder yard is attained with a group of retarders on each classification track, but the cost of such an arrangement would be very high and the capacity afforded would be far in excess of reasonable requirements. It is therefore the practice to design an arrangement for the particular requirements, and as economy of installation requires a minimum number of retarders, one group of retarders usually serves from three to seven or more classification tracks, according to traffic, number of classification tracks, and other factors.

A typical arrangement is as shown in Fig. 10, in which six leads radiate from the hump lead and each lead serves six classification tracks. There are three groups of retarders: First, the hump which controls the speed of cars at the junction switch and as used also to space adjoining cuts; second, an intermediate group which checks the acceleration of cars or cuts on the comparatively steep grades; and third, the final group which reduces the speed to about 3 miles an hour. The speed of cars through the throat of the yard depends upon the retarding value of the last group. In Fig. 11, the Mechanicville yard of the Boston & Maine Railroad, there is shown a total of 17 retarders, or about one retarder to two classification tracks, which is a very efficient arrangement. In order to have each car or cut from the hump reach the clearance point in each classification track in the shortest possible time, within the limits of possible humping speed, it is obvious that the distance from the crest of the hump to the clearance point in the classification track should be a minimum.

One method of shortening this distance is the use of lap switches, which also tend to reduce the number of feet of retarders required. Track scales, also any switches on the hump lead, tend to increase this distance and to increase the number of feet of retarders.

### Grades That Are Recommended

The hump and grades recommended by the American Railway Engineering Association or a modification of these are ordinarily suitable for retarder yards. For yards in the northern part of the United States, where there is considerable cold weather in winter, the hump grade should be 4 per cent, 1 to 1.5 per cent on leads, and 0.25 or 0.30 per cent from last retarder down nearly to the end of the classification tracks; 0.30 per cent is generally assumed as a non-accelerating grade for average conditions, but is subject to considerable variation.

Car friction varies greatly with the type of car, the weight of car, and lading, the temperature, condition of the bearings, the wind pressure, the speed, and the grade, running from 0.25 per cent (5 lb. per ton) for loads to 1.50 per cent (30 lb. per ton) or more for empties. It is a simple matter to provide suitable hump and grades for a yard handling all loads or all empties, but as most yards handle both empties and loads, it is necessary to provide for them or delays in operation would result.

A most unfavorable condition is handling an empty car on a cold winter day. The other extreme is a heavy load on a warm summer day. With mixed traffic, empties, and loads, car retarders afford a simple means of compensating for the difference with a hump of sufficient height to handle an empty car in winter. At several busy retarder yards hot oil under pressure is applied during cold weather to the car journals just before the cars reach the hump, the journal-box lids being raised by the car inspectors in the receiving yards. This method is very satisfactory and prevents the slowing up of operations by a car stalling on one of the leads and the resulting delays which would be critical during peak periods. The journals are warmed somewhat while the train is run from the receiving yard to the hump, which is often some distance; but in very cold weather it is sometimes necessary to run the cars back and forth before humping them.

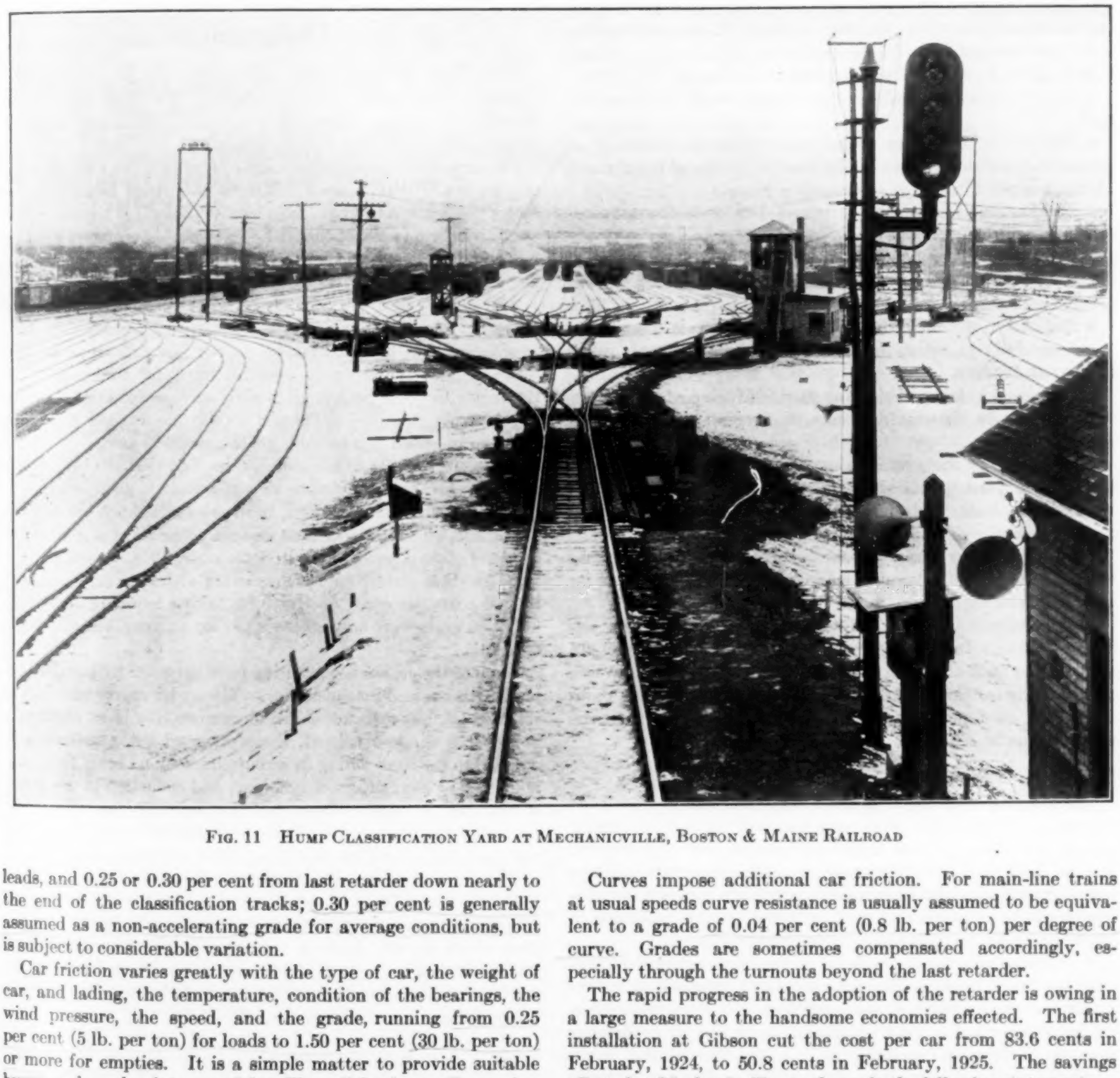

Fig. 11 Hump Classification Yard at Mechanicville, Boston & Maine Railroad

Curves impose additional car friction. For main-line trains at usual speeds curve resistance is usually assumed to be equivalent to a grade of 0.04 per cent (0.8 lb. per ton) per degree of curve. Grades are sometimes compensated accordingly, especially through the turnouts beyond the last retarder.

The rapid progress in the adoption of the retarder is owing in a large measure to the handsome economies effected. The first installation at Gibson cut the cost per car from 83.6 cents in February, 1924, to 50.8 cents in February, 1925. The savings effected at Mechanicville are shown in the following statement:

| | 2 mos., 1927 | 2 mos., 1928 |
|---|---|---|
| Cars received | 50,193 | 51,298 |
| Freight payroll, dollars | 56,621 | 30,961 |
| Cost per car, cents | 112.8 | 60.4 |

| | 2 mos., 1927 | 2 mos., 1928 |
|---|---|---|
| Locomotive repairs, dollars, decrease of | ... | 3151 |
| Fuel, dollars, decrease of | ... | 4355 |
| Hostling, dollars, decrease of | ... | 887 |
| Total saving for two months, dollars | ... | 34,053 |
| Total saving per year, dollars | ... | 221,312 |

### Economy of Retarder Operation

The principal economies resulting from retarder operation may be summarized as follows:

1 Reduction in engine and crew hours. In most yards the humping engine and crew spend only part of the time on humping operations and the rest on making up trains, delivering transfers, or on miscellaneous switching operations. This makes it possible to effect a considerable reduction in the engine hr. per day.

2 Retarder plant available for maximum traffic 24 hours per day.

3 Various flat switching operations at adjacent points or at several stations can be done at the retarder yard and often make a large reduction in engine and crew hours.

4 Elimination of car riders, switch tenders, and other employees and of injuries to these employees.

5 Reduction in damage to cars and lading. On account of the facility of controlling cars by retarders, the humping or coupling of cars at excessive speed is eliminated.

6 Reduction or elimination of pilferage, which is often a big item, especially at night, in a large yard with many car riders and switch tenders.

7 Reduction in labor of cleaning yard. Much coal and similar commodities are shaken from cars on account of coupling at excessive speed.

8 Reduction in the average time required to handle a car or train in the yard. This also tends to reduce the elapsed time between terminals, and thus results in more economical operation on the entire division.

9 Quicker deliveries to shippers. In several cases this has been the subject of favorable comment to railway officials by large shippers.

10 Elimination of accidents and delays resulting from defective brakes. In car-rider yards defective brakes often are not detected until after a car has passed over the hump, in which case the rider is helpless and the car crashes into other cars, damaging both cars and lading, and delaying operations until the wreckage can be removed.

### Cost of Retarder Installation

The cost of a retarder installation varies considerably with the number and gross weight of the cars handled, the height of hump necessary, revision of track layout and grades, and other factors. Also on account of the difference in conditions each yard requires a special study in order to determine whether a retarder installation would be economical. Ordinarily the possible reduction in engine and crew hours is the chief determining factor.

In planning new hump yards for either rider or retarder operation the track layout and grades should be arranged as for retarder operation, which is more efficient and economical than the usual rider hump yard by the reason of the short distance from the hump to the clearance point in the classification track, which naturally shortens the time and the distance required for riders to return to the hump. A yard so constructed and operated at first with riders could easily be equipped for retarders and with minimum expense.

### Conclusion

The car retarder is one of those modern time- and labor-saving devices that have enabled the railways to reduce operating expenses in spite of rising costs of labor and materials. Although the retarder is a recent development, the first commercial installation in the United States was put in service in February, 1926, and nearly all of the apparatus of this first installation is still in service. The design of this first apparatus has been substantially improved, based upon careful observations under service conditions, and the improved design, which has been in service nearly a year, amply meets all requirements, showing that the retarder has successfully passed through the development stage and is now generally considered as an approved device for the efficient and economical operation of hump yards.

## Discussion

Edward E. Regan.[2] The paper covers the operation of car-retarder hump yards very thoroughly. We have one on the New Haven road at Hartford, installed in connection with the construction of the new hump yard there.

Our experience as to the economies resulting from car-retarder installation is that in some instances they were large, but one factor that should be given considerable thought is the size of the yard and the number of cars to be handled. Another is whether all the economies that could be effected in the existing plant had been made before considering retarder installation.

The author lists the number of employees necessary to the operation and maintenance of the plant. Of course, each yard is different, but at Hartford we do not add full crews when a second engine is put on to assist in humping, but require the conductor to cover both engines with only one additional brakeman. When humping is finished we use the retarder operators, who are qualified conductors, on the second engine. With respect to the number of maintainers, we find that one maintainer and his helper are sufficient to keep the plant in good order.

As to the cost per car, on the basis of cars received our costs at Cedar Hill with rider operation and including all men in the yard as based on two typical days in September, 1928, were about the same as those shown for Mechanicville with retarder operation, i.e., 60 cents per car. At Hartford, taking humping operations only, our costs were only 23 cents per car as compared with their 60 cents.

Some of the economies resulting from car-retarder installations have been stressed by the author. The writer agrees with him in this respect, but does not think there were very large economies in some of the items listed, those excepted being reduction in damage to cars and lading (a recent check by us bears this out), reduction or elimination of pilferage, and reduction in the labor of cleaning the yard. These last two especially are under the control of the supervisory officers and should be well in hand in any yard, and therefore should not show any great economy.

The writer does not wish to give the impression that the New Haven is not in favor of retarder yards, but has desired to call attention to some of that company's experience in figuring economies which did not show up very large in the items questioned and would not show such large economies as those listed by the Boston & Maine, possibly owing to the fact that our present man-ridden humps are operating very efficiently.

Charles E. Barba[3]. Since the earning capacity of our transportation systems is, in a measure, equal to the amount of tonnage that can be moved efficiently, yard and terminal facilities un-

[2] General Superintendent, New York, New Haven & Hartford Railroad, New Haven, Conn.

[3] Mechanical Engineer, Boston & Maine Railroad, North Billerica, Mass. Mem. A.S.M.E.

doubtedly control the amount of cars that can be economically classified for road service. The paper very ably describes the methods by which the efficiency of yard operation can be increased, and when we consider that a period of nearly forty years elapsed before any radical change occurred in speeding up yard operations, the following historic facts may be of interest:

Probably the first published statements about gravity yards were made by Professor Kopcke, of the Dresden Polytechnic School, in 1871, when he described the yard at Dresden, which has been in use since 1846. It had its beginning from a natural grade in the main line of 1 in 55, and it is estimated that it was possible to classify at that time (1871) 720 cars in 24 hours. There have also been gravity yards at Leipzig since 1858 and at Zwickau since 1861.

In England, during the year 1873, Mr. Footner claims to have designed the first yard where cars were to be classified by gravity without the use of locomotives or horse power. At this time the London & Northwestern R.R. found that their business at Edgehill, near Liverpool, had quadrupled, but the yard facilities had only been doubled. The company owned land on the north side of the railroad which was available for extensions, but to reduce it to the grade of the main line would have made necessary a large amount of excavation, and it was this fact that led Mr. Footner to design the yards for gravity shifting. It was thought necessary to have some means of stopping cars which might get beyond control of the shunters. Mr. Footner designed what was known as the "chain drag." This consisted of a heavy iron chain placed in a wrought-iron tank between and below the level of the rails; a steel hook attached to the cable was fixed in a loose socket at the height of the car axles and was controlled by a lever. The hook was lowered if the car was intended to pass, but raised if it were desired to stop the car, so that the hook caught the car axles and the heavy chain was dragged over the ballast, thus quickly stopping the cars. It is stated that during the 12 years previous to 1889 it was used 135 times, and that it always stopped the car with no damage to it or to the apparatus itself.

In France gravity yards were first used in 1863 at Terre Noire, near St. Etienne.

The summit or hump yard was used in Germany at Speldorf in 1876 and a little later at Gray, near Essen. In France it was used on the P.L.&M.R.R. in 1888. In the United States it has several claimants for priority. The Honey Pot Yard on the Sunbury Division was built about 1888, and it is also claimed that the Coxton, Pa., Yard on the L.V.R.R. antedates the Honey Pot Yard by several years.

The first artificial hump constructed on the Pennsylvania Railroad, and probably in the United States, was constructed about two miles south of Greensburg, Pa., in the years 1882 and 1883.

R. J. Hammond.[4] The retarder that the author described is an old-type machine.

Mr. Regan spoke of the number of men required. At Boston we have practically the same organization as he outlined for Hartford, that is, one conductor at the hump, regardless of the number of engines. At Mechanicville, on account of the difference in character of the work, we use a conductor with each engine, the engines being used not only at the hump, but to switch in the ice-house and transfer yards, as well as to make delivery of trains to other railroads.

In making a comparison of costs no true result can be reached unless the work done at each yard is the same. Mr. Regan mentioned the cost at one of his stations. The writer does not know how much of the total terminal work is included in his figure. The cost that the author gave was for the period shortly after the retarders were put into service. The last two months our cost has been about 47.2 cents per car received. That is our entire terminal cost, and includes the switching of the transfer, repair tracks, ice house, making up of locals, engine-house work, as well as the hump cost, and in addition includes the cost of industrial-plant switching for private concerns.

The operation at Cedar Hill which Mr. Regan described is different from what it originally was at Mechanicville, as at Cedar Hill all the switches are power-operated, while at Mechanicville they were formerly thrown by hand; the actual labor cost at Cedar Hill, of course, being lower, as one man would do the work from a tower which would require many men to do by hand.

[4] Assistant to President, Boston & Maine Railroad, Boston, Mass.

# Locomotive Sparks

By L. W. Wallace,[1] Washington, D. C.

*The annual loss due to fires alleged to have been started by locomotive sparks is stated in the paper to be approximately 12 million dollars. Numerous locomotive and laboratory tests have been made for the purpose of determining the behavior of such sparks, and the author presents some of the findings relating to the subject. It is his belief that under the most favorable circumstances it is very unlikely that a spark of sufficient size and temperature ever reaches the ground in a condition that will ignite even the most inflammable material beyond 65 ft. from the center of the track. Further, there is no direct relationship between wind velocity and spark distribution. Other facts which the author sets forth clearly disclose that it is exceedingly difficult to ignite inflammables with sparks of the size that pass through the ordinary locomotive netting, even at temperatures far exceeding those at which they escape from the locomotive stack. He also discusses other factors with regard to the distribution of sparks, their behavior under conditions of high temperature, color as a basis for judging the temperature of sparks, fire-weather forecasts, moisture content as a reliable index to a degree of inflammability, etc. He is of the opinion that sufficient data have now been accumulated from which fixed laws relating to the behavior of locomotive sparks may be formulated.*

IN THE discussion of the subject of locomotive sparks before a meeting of The American Society of Mechanical Engineers a few years ago, a prominent forester said that before the attitude of the forester can be changed, tests as to the distribution of sparks of fire-bearing size, under conditions of high temperature, low relative humidity of atmosphere, and high wind velocity, must be made. Apparently this forester was not acquainted with all the experimental work which had been done on the subject up to that time.

Numerous locomotive road and laboratory tests have been made for the purpose of determining the behavior of locomotive sparks. There are now available experimental data bearing upon all the points referred to by the forester quoted.

It will be the author's purpose to disclose in this paper some of the findings relating to the subject.

Before proceeding it is well to indicate whether or not the subject is of sufficient importance to warrant discussion and investigation. Federal and State forest officials, in cooperation, have compiled over a period of nine years a record of forest fires by causes. They have formulated eight classifications. The eight classes and the percentage of fires caused by each for a nine-year average are:

| | Per cent | | Per cent |
|---|---|---|---|
| Lumbering | 5.9 | Burning brush | 15.1 |
| Lightning | 7.3 | Unknown | 15.9 |
| Miscellaneous | 7.3 | Camp fires and smokers | 17.5 |
| Railways | 12.8 | Incendiary | 18.2 |

The actual fire damage to forests in 1924 was placed at \$38,000,000. If the 12.8 per cent of fires charged to railways caused the same percentage of damage, they were accountable for \$4,860,000. In official and lay minds this is probably the amount charged to railways. It is an unfair charge, however, because under the railway classification are included all fires starting on the right of way, regardless of the source. Such fires may originate from locomotive stacks and ash pans, or from a cigar or cigarette thrown from a train by a passenger or employee, or dropped by a trespasser. There are numerous ways by which a fire may start on the right of way, and for which the railway is not responsible and which it cannot prevent. Therefore under the present system of classification railways are being officially charged with causing more fires than they themselves are guilty of. This situation should be corrected as it is leading to erroneous impressions as to the liability of railways concerning forest fires.

In addition to the estimated amount of \$4,860,000 forest loss due to fires alleged to have been started by locomotive sparks, which is contended to be erroneous, the railways are subjected to a heavy expense due to the settlement of claims, payment of awards made by juries, and the cost of investigation and litigation resulting from fire cases.

It has been estimated that the total annual cost of fires alleged to have been caused by locomotive sparks is in the order of \$12,000,000. Therefore the spark problem is an important one, and the determination of the behavior of a spark is of such significance as to justify the expenditure of a large amount of effort, time, and money.

### Distribution of Locomotive Sparks

Locomotive sparks are ejected from the stacks of locomotives with considerable force and velocity. This force and velocity affect their distribution. There are other factors which also affect the distances sparks will travel. These are the force and weight of the spark, the force of gravitation, the speed of the train, the force of exhaust, the direction and velocity of the wind, and currents of air created by the movement of the train.

Since so many factors influence the distribution of sparks, no one is justified in drawing any general conclusions from mere observation. Accurate facts as to the distribution of sparks can be determined only by careful experimentation. This has been done, resulting in the following determinations.

1 The greatest amount of material ejected from locomotive stacks falls within 50 ft. of the center of the track. Something like 80 per cent of all the material falls within 50 ft., whereas 98 per cent falls within 100 ft. of the center of the track.

2 The material which falls beyond 70 ft. of the center of the track is very fine and of a sooty character.

3 Sparks of definite weight and bulk fall within 65 ft. of the center of the track. Indeed, by far the greatest number of these fall within 50 ft. No spark of sufficient weight and bulk to carry the amount of heat necessary to ignite the most inflammable material has been caught as far as 50 ft. Indeed, no spark, the temperature of which was gaged to be as high as 1200 deg. fahr., has been caught beyond 25 ft. from the center of the track.

From the numerous observations made, it is the author's deliberate judgment that under the most favorable circumstances it is very unlikely that a spark of sufficient size and temperature ever reaches the ground in a condition which will ignite the most inflammable material beyond 65 ft.

It is an interesting fact that the velocity of wind does not have a material influence upon the distribution sparks. That is to say, if under a wind velocity of 10 miles an hour bulky sparks are caught as far as 25 ft. from the track, it does not follow that if the wind velocity is increased to 20 miles per hour bulky sparks will be caught at 50 ft. There is no direct relationship between

[1] Executive Secretary, American Engineering Council. Mem. A.S.M.E.

Contributed by the Railroad Division and presented at the Spring Meeting, Pittsburgh, Pa., May 14 to 17, 1928, of The American Society of Mechanical Engineers.

wind velocity and spark distribution. As the wind velocity increases, however, there is a slightly wider distribution of the lighter and sooty material.

This fact confounds people. They do not understand it. The reason is readily appreciated when it is realized that the numerous factors enumerated above control the action of a spark after it leaves the stack—gravity being the predominating one, perhaps.

### High Temperatures

The forester cited earlier queried as to the behavior of a spark under conditions of high temperature. It is taken that he meant atmospheric temperature. Tests have been made with atmospheric temperatures ranging from freezing or below to the normal high temperatures prevailing in the summer. Naturally, as a spark travels through cold air it cools more rapidly than when traveling through hot air, and it is more likely to ignite a substance that is very warm than one which is cold. But under the most favorable atmospheric conditions a spark retains heat for only a very few seconds.

So low is the temperature of a spark upon leaving the stack and so rapidly does it cool, that conditions have to be extraordinarily favorable for it to ignite any inflammable upon reaching the ground, and certainly it does not reach the ground in such a state as to ignite inflammables beyond 50 ft. from the center of the track under high atmospheric temperatures.

Few sparks reach the ground at a temperature as high as 1200 deg. fahr., and those which have been caught at such a temperature fell within 30 ft. of the center of the track.

Laboratory tests have disclosed that a spark must be larger than $^3/_{16}$ in., and at a temperature higher than 1400 deg. fahr., to ignite excelsior. It required a spark $^3/_8$ in. in size and at a temperature of 1400 deg. fahr., to slightly char grass such as the blue grass of Kentucky and Indiana. Such grass does not show a tendency to burn until a $^1/_2$-in. spark at 1600 deg. fahr. is applied. It does not blaze until a spark $^3/_8$ in. or larger, at 1800 deg. fahr. is applied. Sparks $^3/_8$ in. in size do not cause the fuzzy material on the surface of old shingles to flash except at a temperature of 1700 deg. fahr. or above. Practically the same results obtain with new shingles.

Sparks $^3/_{16}$ in. in size produce only a slight char at 1900 deg. fahr. on old shingles, and at 1700 deg. fahr., they cause only a slight discoloration on new shingles. In fact, no spark that can be passed through any netting which is commonly used in locomotives, even when heated to 1700 deg. fahr., will ignite such combustible materials as shingles, sawdust, or light, friable woods.

It will be realized, of course, that temperatures of 1700 to 1900 deg. fahr. are comparable to low firebox temperatures, consequently it is not reasonable to expect that a spark ever leaves the locomotive stack at any such temperature. The average smokebox temperature under the worst conditions is in the order of 750 deg. fahr., or lower.

Burning coal approximately one inch square, taken from a furnace temperature of 1700 to 1900 deg. fahr., and immediately applied to a shingle-roof section, failed to cause ignition. It was not until a piece of coal in the order of three or four inches square was applied that the roof section was ignited, and then it required 42 minutes for a hole to appear in the section.

These facts clearly disclose that it is exceedingly difficult to ignite inflammable materials with sparks of the size that pass through the ordinary locomotive netting, even at temperatures far exceeding those at which they escape from a locomotive stack.

Then, too, sparks cool very rapidly. Two time intervals have been applied. First, the time of visual disappearance of heat, meaning the time in seconds from the removal of a spark from a furnace until no heat can be detected through the appearance of color or smoke; and second, the total time until all the heat in the spark is gone as determined by grasping it with the fingers, the time elapsed being that from the moment the spark was withdrawn until grasped with the fingers.

At 1400 deg. fahr. the visual disappearance of heat from sparks that pass through $^3/_{16} \times {^3/_4}$-in. netting, is 5.4 seconds; sparks passing through $2^1/_2 \times 2^1/_2$-in. square mesh netting, 7.5 seconds; and sparks passing through $^3/_8$-in. netting, 21.2 seconds.

At 1900 deg. fahr., the visual disappearance of heat occurs with $^3/_{16}$-in. sparks in 10.2 seconds, with $^1/_4$-in. sparks in 14.8 seconds, and with $^3/_8$-in. sparks in 21 seconds. At 1300 deg. fahr. the average time in seconds of total disappearance of heat is 53 seconds for sparks that pass through $3 \times 3$-in. square mesh netting and 67 seconds for sparks that pass through $2^1/_2 \times 2^1/_2$-in. square mesh netting; all of the foregoing under the condition of no wind.

The application of wind reduces these time intervals. Under some circumstances with the increase of wind velocity from zero up to the order of four miles per hour there is a slight indication that the time of cooling is increased. This does not appear to be the case under all circumstances, for under some conditions any increase in the velocity of wind from zero decreases the time of cooling. Under all circumstances it may be said that as the velocity of wind increases beyond four or five miles per hour, there is a rapid decrease in cooling time. That is to say, as the wind velocity increases beyond four miles per hour a spark is cooled as the wind increases, and not fanned and made hotter as some believe and contend.

### Color of Sparks

Oftentimes color is used as the basis for judging the temperature or ignition properties of a spark. It is therefore important that all concerned have some definite idea of the relationship between the color and temperature of sparks.

Many observations have been made in laboratories under both natural and artificial light to determine this relationship. As a result of these observations such zones as the following may be established:

From 0 to 1000 deg. fahr. sparks are black. Occasionally at 1000 deg. there may be detected a faint red tint in the inner surface. The outer surface is black.

From 1100 to 1200 deg. sparks are faint or dull to slightly dark red.

From 1300 to 1400 deg. sparks are dark red with a frequent tendency to bright red at latter temperature.

From 1500 to 1600 deg. sparks are bright red. At the latter temperature a slight glow on the surface of the spark occasionally occurs.

From 1700 to 1900 deg. sparks are glowing red to glowing white. Many sparks when heated to 1800 and 1900 deg. will become enveloped in an intense short, white flame.

Due to the fact that sparks $^3/_{16}$ in. or $^1/_4$ in. in size cool very rapidly, it is a matter of a very few seconds after exposure to the atmosphere until there is a marked change in color. For instance, $^3/_{16}$-in. sparks heated to 1400 deg. fahr., and dropped on old shingles were black in less than three seconds; at 1700 deg., black in about four seconds; at 1900 deg., black in approximately seven seconds. When bright or glowing red they almost always became black on or before reaching the ground.

### Atmospheric Conditions

During the last few years much has been said about fire weather. Foresters are beginning to rely upon Weather Bureau reports as an indication of the likelihood of inception of

fires. The Weather Bureau now makes fire-weather forecasts which are highly regarded by foresters and others. The forecasts include information relating to:

Conditions actually causing fires, as storms accompanied by lightning;

Conditions favorable for inception of fires however caused, such as unusually low humidity and high temperature;

Conditions favorable to the spreading of small fires, such as hot winds and winds from moderate to high velocity.

These forecasts are undoubtedly helpful. However, they are not infallible. Moreover forecasts based upon general information covering a wide area may not be accurate for a particular locality because the topography and other influences may produce a condition of temperature, wind, precipitation, and humidity in restricted localities materially different from the broader area. Consequently the weather readings made at Spokane, Washington, for example, may be entirely different from actual conditions prevailing at Burke, Idaho, some thirty miles away, although included in the forecast area covered by the Bureau at Spokane. It would be possible to have high temperature, dryness, and no wind at Spokane, while at Burke, due to the marked differences in topography and elevation, the conditions would be entirely unlike those at Spokane. The Weather Bureau is recognizing this, and in important forest areas is correcting the situation by taking readings in many strategic places within these areas.

The moisture content of inflammables and the relative humidity of the atmosphere are also receiving marked attention in fire-prevention and control work. These factors are likewise creeping into litigation growing out of fires alleged to have been caused by locomotive sparks. They are undoubtedly important factors if correctly understood and applied. However, there seems to be some confusion in relation to these factors. Some seem to have the idea that low relative humidity necessarily indicates a state of inflammability. This is not true. There may be a low degree of relative humidity and at the same time a high moisture content of inflammables.

The moisture content of inflammables has much more to do with the likelihood of igniting such inflammables than existing relative humidity. Naturally moisture content is affected by relative humidity, but it does not change instantaneously with the change in humidity. Therefore relative humidity is not an accurate measure of the moisture content and hence of inflammability.

The Forest Service has made the following classifications by moisture content of the inflammability of duff, the matted pine needles and debris on forest floors:

| Moisture content, per cent | Degree of inflammability |
|---|---|
| 1 to $7^1/_2$ | Extreme |
| $7^1/_2$ to 10 | High |
| 10 to 14 | Medium |
| 14 to 18 | Very low |
| 18 to 26 | None |

This tabulation shows that duff must have a relatively low moisture content before it can be classified as highly inflammable. It also shows that by increasing the moisture content of duff from 10 to 26 per cent, the degree of inflammability passes from medium to a state of non-inflammability.

Experiments have been made with sparks $^3/_{16}$ in. in size to determine the effect of relative humidity. The tests were made with sparks ranging in temperature from 1400 to 1900 deg. fahr., with relative humidity varying from 35 to 60 per cent, and with wind ranging from zero to five miles per hour. Under these conditions the sparks were placed upon dry shingles. The results warrant the conclusion that relative humidity can be reduced from 60 to 25 per cent without any material effect upon the action of $^3/_{16}$-in. sparks, under constant conditions.

The general conclusion drawn from all the work thus far done as to the relationship between relative humidity and moisture content is that moisture content is a more reliable index to the degree of inflammability then relative humidity, and hence should be given greater credence in litigation.

### Character of Coal

The investigations, some of the results of which are herein indicated, have been made with cinders formed from various types of coal. In the last analysis a locomotive spark is largely carbon. Since the characteristics of carbon are approximately the same regardless of the coal from which it is formed, it is reasonable to expect the same kind of performance from all sparks. It is to be realized that the foregoing is a general broad statement and is not strictly scientifically true, but it is sufficiently accurate for all practical purposes. A test made with sparks from various types of coal substantiates the general statement. Tests have been made with sparks from low-grade and high-grade bituminous and anthracite coals, and approximately the same relative results were obtained with all sparks under the same set of conditions. It is a fair conclusion that under like atmospheric conditions and spark characteristics the behavior of sparks is approximately the same regardless of the character of the coal from which the sparks are derived.

Although tens of thousands of observations have been made while conducting locomotive road and laboratory tests, it is realized that sufficient data have not been accumulated from which to formulate any fixed laws relating to the behavior of locomotive sparks. However, these observations have so illuminated the subject as to warrant the conclusion that fundamental and incontrovertible laws may be laid down. Ways and means ought to be provided for intensifying on a large scale the scientific work that has been done and for widely disseminating the facts so derived. A procedure of this character would remove a great deal of public misinformation and prejudice, and contribute to the well-being of the railway companies.

In this connection a former member of a State Supreme Court, after being advised of the results of the investigations referred to, said, in substance: "The railroads should see to it that the great work which has been done is continued. It is scientifically demonstrated that the much reviled spark has generally had nothing to do in causing most of those fires alleged to have been started by locomotive sparks. If this scientific work is continued to its logical conclusion it would be accepted in court as prima facie evidence as are weather reports and therefore without the prerogative of the jury to pass arbitrary judgment."

## Discussion

H. G. Pinniger.[2] The writer agrees with the author that the railroads of America have in the past been forced to pay out large sums of money in settlement and to satisfy judgments for fire losses alleged to have been set out by locomotive sparks. Most defendants were satisfied that the fires originated from some other source, but due to lack of convincing proof the courts permitted juries to guess that the locomotive sparks would carry hundreds of feet beyond the railroad right of way and set up fires.

The writer's experience has been that the public at large through misinformation and prejudice has been responsible for charging such fires to locomotive sparks, and he is in accord with the author's statement that if this scientific work were once continued to its logical conclusion it would be accepted in court as

[2] District Claim Agent, Michigan Central Railroad Co., Detroit, Mich.

prima facie evidence, as are weather reports, and therefore do away with the prerogative of the jury to pass arbitrary judgment.

W. F. Every.[3] The statement from forestry sources that 12.8 per cent of all fires have their origin from the operation of railways is not readily accepted. Many large fires have their origin in places remote from permanent habitation and are too frequently charged as of railway origin through lack of close investigation to determine whether the fires reached the railway right of way by back fire, or were driven by high winds across the tracks.

However, the estimate of total annual cost by fires alleged to have been caused by locomotive sparks, placed at $12,000,000, is conservative, and doubtless low.

The claims presented against the railroads operating in Northern Minnesota growing out of what is commonly known as the Northern Minnesota forest fire of October 12, 1918, amounted to more than $50,000,000 and cost four railroads much more than the amount of $12,000,000 estimated as an annual cost to all railroads, notwithstanding the contention and fair showing of the railroads that the fire had its origin at several points far remote from the railway, and was destructive only because of a cyclonic wind on that date.

There is left no question as to the importance of pointing out the comparatively low danger from locomotive sparks. The general charge that a locomotive is a fire-setting agency had its beginning with the wood-burning engine, which emitted a spark entirely different from the present so-called spark from a coal-burning locomotive. The layman does not differentiate between a spark that is indeed a fire-carrying agency, and the cinder which retains only a small amount of heat sufficient to possess the fire color. The average laymen, before whom a railway must appear in defense of a charge of fire having been set by an engine, have no conception of the mechanical devices which prevent the escape of destructive material from the smokestack and ashpan. This wide general belief that a coal engine is a constant fire-setting agency is not surprising. It is common knowledge that sparks are emitted. Some fires are set. These are in highly inflammable material. As pointed out by the author, the other causes are not considered. The unknown causes are readily charged to locomotive sparks from failure to recognize other probable causes.

There is a great work to be done, worthy of much labor and expenditure of money, in the distribution of definite data already at hand, as furnished in the author's book on "Fire Losses—Locomotive Sparks."

It has been the writer's privilege to witness the intense interest displayed by courts, court attachés, juries, lawyers, and others in the testimony and demonstrations given by the author on data he has accumulated showing the low inflammability of sparks. In a great loss involving many people, and much sentiment and sympathy, the writer has seen these men and women spellbound—convinced. Furthermore, mechanical men are so clearly assisted by these actual experiments and data that new ways and means are sought to eliminate the escape of any cinder of size and heat sufficient to set fire.

It is but fair to say that only in recent years has the immense value of the research on this subject been appreciated, and, as suggested, the value of this enlightenment has been confined to a few localities. It is not generally known in its expert relation to the defense of law suits where railroad origin of fire is rightly denied.

[3] General Claim Agent, Northern Pacific Railway Co., St. Paul, Minn.

Stan D. Donnelly.[4] The writer has found this paper intensely interesting, particularly because he has occasionally been called upon to defend a suit for a railroad company in which it was claimed that a railroad locomotive had set fire to property.

Within the past year the writer's firm has defended the Chicago Great Western Railroad Company in a suit for damages in which the plaintiffs claimed that the railroad company was responsible for starting a fire resulting in the burning of certain buildings. The claim was that sparks thrown from the locomotive stack had set the fire, and very large damages were asked.

The case was tried in the United States District Court at St. Paul, Minn. If locomotive sparks had set the fire, they would have been required to travel through the air a distance of nearly 150 feet from the railroad right of way to the point where the fire started. One of the principal defenses in the case was that it was impossible for sparks to have been emitted from the smoke stack, traveled that distance, and set the fire. Upon this point the author testified on behalf of the defendant. He was permitted by the court to testify fully as to the behavior of locomotive sparks, his experiments with relation thereto, the results he obtained, and his conclusions. Just before the trial commenced he conducted an experiment which consisted of operating a train of the same railroad company under weather, wind, and grade conditions similar to those existing at the time and place the fire was alleged to have been set by the locomotive. He was permitted to give the results of that particular experiment. With his excellent help, it was possible to convince the jury that the fire was not and could not have been caused by sparks emitted from the stack of the locomotive as claimed by the plaintiff. The jury returned a verdict in favor of the defendant railroad company.

This jury was composed of farmers and business men, all men of considerable experience and of mature years. They apparently had no difficulty in agreeing with the author, notwithstanding the fact that the supreme-court decisions of many states, including Minnesota, have permitted verdicts to stand against railroad companies for large damages on account of fires occurring under circumstances and conditions similar to the claims of plaintiffs in this action.

It is the opinion of the writer and his associates that the author has been doing a great work, and that he is absolutely correct in his theories and conclusions on the subject of the behavior of locomotive sparks. Although very occasionally a passing railway locomotive may have started fires through emission of sparks from a stack (but more likely through coals falling from the firebox), the writer feels that heretofore railroad companies have been called upon to pay enormous sums of money on account of fires with which locomotive sparks had absolutely nothing to do.

T. W. Norcross.[5] In general, the conclusions of the Forest Service as to the distances from the track at which fire-starting sparks will fall are in rather close harmony with the conclusions of the author. It is believed that except for conditions of heavy grades and steep slopes, fireproofing of a railroad right of way for a horizontal distance of about 50 ft. on each side of a track is usually ample. The sparks which fall within 50 ft. horizontally from the center of the track include those which start forest fires, and and unless this area can be adequately fireproofed or the fire-starting sparks eliminated, the starting of forest fires will continue.

Very possibly locomotive sparks may not have been responsible

[4] Oppenheimer, Dickson, Hodgson, Brown, and Donnelly, Attorneys-at-Law. St. Paul, Minn.

[5] Chief Engineer, U. S. Department of Agriculture, Forest Service, Washington, D. C.

for forest fires in all cases where such sparks were given as the cause. No conclusive evidence, however, has been presented to support the statement quoted by the author that it has been "scientifically demonstrated that the much-reviled spark has generally had nothing to do in causing most of those fires alleged have been started by locomotive sparks."

It has been the experience of the Forest Service that much of the trouble experienced from sparks has been due to equipment that is out of order. Frequent and regular inspection to insure that spark-arresting devices are in standard condition has been found essential. Devices which do not readily get out of order are likewise important from this standpoint.

The nature of the material in which sparks fall is a matter of great importance. Dry shingles are not comparable to the dry, tinder-like grasses, dry leaves, and dry, rotten wood which are often found on rights of way which have not been cleaned. Rotten wood is now considered the most dangerous of all materials found on forest land.

William Elmer.[6] The effort made by our railroads to clean the ballast is tremendous. Those who are not in contact with the problem do not seem to appreciate the amount of money involved, especially where there is heavy traffic. Hundreds of men and thousands of dollars' worth of equipment are required, and the effort is enormous.

The amount of information which the writer has been able to obtain on the subject is but a portion of that which is in the possession of the maintenance man who started in that department and has followed it.

Perhaps the major reason for the source of trouble is the fouling from locomotive sparks. This can be noticed very clearly in cuts as against fills. The amount of leakage from coal cars of course does not vary whether the car is going through a cut or on a fill, but the amount of wind that can take away the sparks is greater on a fill than in a cut. The sparks fall more nearly vertical in the cut than on the fill.

In some instances, according to supervisors, the evidence indicates that on some parts of a railroad the locomotive sparks are the chief cause of fouling of the ballast.

In addition to the fire hazard the thought occurs to the writer that if something could be done to reduce locomotive sparks, there would result to the railroads themselves a saving of many dollars in the cleaning of ballast and in the cost of keeping the drainage conditions as they should be.

[6] Special Engineer, Pennsylvania R.R. Co., Philadelphia, Pa. Mem. A.S.M.E.

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# Increasing the Production of Cotton Padders

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*When floor space becomes cramped and production throttled in certain departments of a growing business, the management is confronted with the task of enlarging capacity.*

*The author discloses the procedure followed in the dye house of a cotton-finishing plant for increasing production per man-hour and per machine-hour without investment for additional equipment.*

*He describes the psychological background and existing handicaps, and outlines methods of overcoming both with results of noteworthy improvements.*

EVERY cotton-goods finishing plant has, at rush times, experienced the annoying problem of putting a sufficient amount of material through one or more departments. In the course of changing business, no finishing plant or organization can be made like the "wonderful one-hoss shay"—a finished and homogeneous whole, perfectly balanced and all parts equally serviceable and functioning as planned.

Consequently, as the rush of business begins, the strength of the entire chain is measured by its weakest link. It is realized that there is a bottle-neck effect, and that work piles up in front of certain processes. Even then it is doubtful if the extent to which production on other operations is curtailed can be fully comprehended.

The usual old-fashioned method of overcoming such a condition is to enlarge the department by providing more floor space and placing additional equipment—frequently requiring large outlays of money. Spending money, unless warranted, is attempted suicide. One of the foremost principles advocated by the late Henry L. Gantt was to refrain from enlargement until maximum production was obtained with equipment in use, as determined by a thorough, scientific investigation.

In this paper a practical example is given showing certain conditions in one of the departments of a cotton-goods bleachery, how the problem was approached and worked out, and the results obtained.

It had been necessary to operate the direct-color padders considerably overtime during the busy season because of lack of space and equipment. The engineering department had included in its program a plan to study the operation of these machines for the purpose of determining what should be done. This work was started at once, hoping that methods might be developed whereby overtime at least could be entirely eliminated.

The foreman was of the old school—a good color man of considerable experience who took a personal pride in the appearance of his department, the quality of his work, and the welfare of his men. He had asked for task and bonus in his department, saying that he did not believe any increase in production possible, but that he was anxious for his men to receive pay on a par with the best-paid workers in the plant.

He was assured that the management would pay a bonus based on a task of what would be considered a fair day's work regardless of existing production, such task to be determined by means of a thorough and detailed analysis of operations. If these studies showed that, by means of mechanical applications or by different divisions of labor, increased production would result, he would be asked to install them.

To all this the foreman readily agreed, and investigations immediately started.

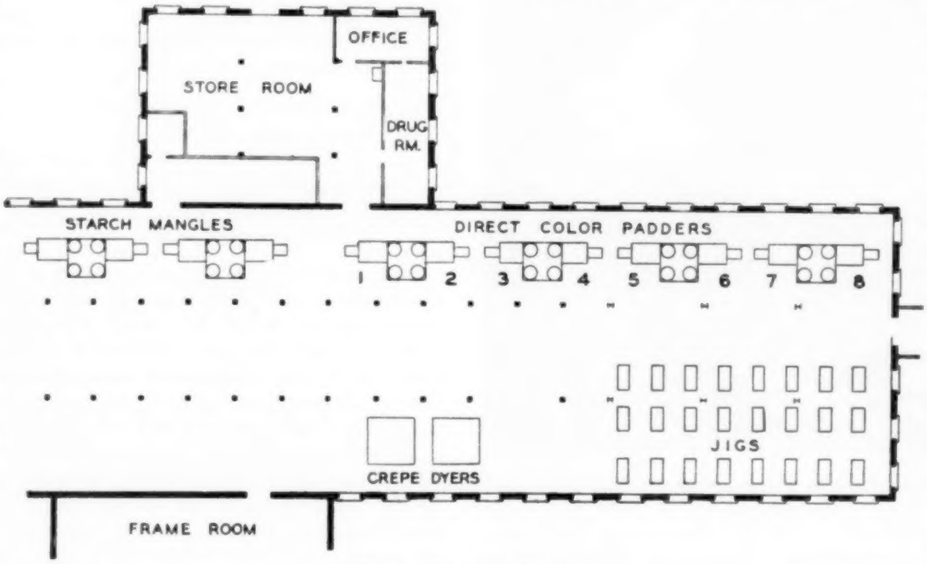


Fig. 1 Machine Layout

### Conditions As Found

The following will give a brief outline of conditions found in the department:

1 The material was received from the dry cans, plaited into box trucks of approximately 4000 yards each. The padders pulled directly from these boxes and delivered in 1000-yard rolls for drying.

2 The machine layout was good (Fig. 1), the padders being arranged in a good light on one side of the room, while the boxes containing work ahead were stored on the other side. Each machine was equipped with two 150-gallon tubs so that dye solution could be prepared in advance in one tub while the machine was drawing from the other.

3 The padders were so designed that when batching on a shell it was necessary, each time the machine was started, to give the shell a turn in order to overcome its inertia. The starting lever being on the entering side, the helper had to be on hand at the take-off side to give the roll the required twist when the operator was ready to start.

4 The organization, together with the duties of the various individuals briefly outlined, was:

| | |
|---|---|
| 1 Second hand | Supervising |
| 1 Drug man | Weighing out ingredients for dye bath |
| 2 Floor men | Supplying cloth as planned by foreman |
| 8 Operators | Running machines<br>Washing machines<br>Washing tubs |

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8 Helpers........
- Getting dye solution
- Assisting in starting rolls
- Assisting in removing rolls
- Delivering complete work for drying
- Drying patches (or swatches) at tenter frames
- Taking patch for foreman's approval before proceeding with the dyeing of the lot.

### Analysis of Delays

After a brief survey, it appeared that the machines were producing at nearly full capacity, but considerable idleness of man time was evident. The real problem, however, was to increase production per machine-hour before considering output per man-hour. Consequently, care had to be exercised that man time should not be filled to the extent that poor service would result

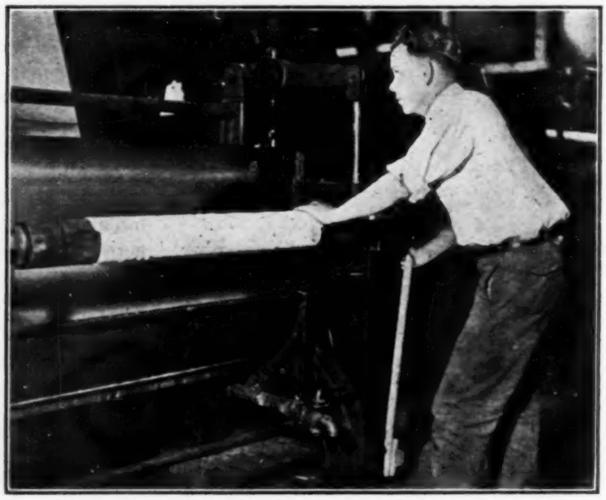

Fig. 2 Starting Machine From Delivery Side Without Assistance

in machine delays. Accordingly idleness was considered in two groups:

Group I. Machine delays, the elimination of which would increase production per machine-hour; and

Group II. Idle man time, the elimination of which would increase output per man-hour.

Under Group I, machine delays were listed as follows:

1. Incorrect speeds of machines. No two machines were running at the same speed, although a definite speed had been established for each class of goods.
2. Washing the tub. The operator did this, permitting the machine to stand idle while doing so. If another were designated to wash the tub while the machine was still in operation, the time thus saved would mean more yards by the end of the day.
3. Waiting for the dye solution on every shade. This resulted because the helper always delivered the final roll before obtaining the color for the next shade.
4. Patches were dried at the tenter frame. The walk there and back required a great deal of time, considering that there were a hundred or more patches each day. A patch drier would eliminate this.
5. Miscellaneous delays resulting from lack of interest in the work were frequent. It was believed that a wage incentive would minimize these.

Under Group II, in the analysis of idle man time, it was found that the delays were numerous, variable in length, and difficult to classify. One man frequently waiting for another indicated poor distribution of labor and lack of co-operation.

### Developing Plans

In view of this, it was decided to classify the duties rather than the idleness of each man, and to plan a new distribution of labor to a new type of organization. The padder being the basis of work, the operation should center around it. The principal duty of the operator should be to keep it producing, machine delays as classified in Group I being avoided. Then, in order that the operator might work efficiently, all idle time had to be eliminated and a full-time job laid out for him. To do this, conditions had to be such as to make him as independent of the rest of the organization as possible. Those supplying the machine with materials had to do so in sufficient time to permit him to have all material when wanted; and all joint operations which required the assistance of others had to be altered so that they might be performed singly.

The following duties were those wherein he was jointly or entirely dependent upon others:

1. Supplying of goods to be dyed
2. Supplying the dye solution
3. Delivering the finished work for drying
4. Drying the patch and having it approved
5. Starting a roll
6. Removing a finished roll.

For the first three of these, the operator was entirely dependent upon others; but with good supply men and truckers the work could be planned so that there would be no delays.

Fourth, drying the patch and having it approved had always been done by the helper, while the operator, with nothing else to do, sat down and waited for the foreman's authorization to proceed. There was no doubt that the more responsible operator would do it more quickly if this were required of him.

Fifth, the helper always assisted in starting the roll because the starting lever was on the entering side of the machine and it was necessary for some one to be on the take-off side to give the roll momentum. The solution was simple. It was only necessary to put an additional starting lever on the take-off side, so that the operator had but to start the next roll from the same position as where he had removed the last (see Fig. 2).

Sixth, removing the roll. A thousand yards of wet cloth in a roll was heavy, and it seemed that assistance here would be necessary. The machine was so constructed that if the roll were not removed carefully, it would hit the side and fall to the floor. The aisle did not permit room for extension arms and the problem was annoying. Finally, the idea was conceived of placing a mechanical hand in the form of a support to hold one end of the center bar while the other end could be swung slowly and carefully out over the aisle and the roll thus lowered to the truck and there left for the trucker to deliver for drying.

Accordingly all plans were laid to operate the padder without a helper. Four of his duties were to be performed by the operator: namely, drying patches, having patches approved, starting a new roll, and removing the finished roll. There remained the supplying of dye solution and the delivering of finished rolls for drying. It was evident that not only were helpers not needed, but that their remaining duties should fall into two distinct jobs, trucking and supplying dye solution; and to these should be added that of washing the tubs.

This in general took care of the principal operations, but a number of minor details had to be worked out, such as the making of roll tags, labeling of buckets, adding of steam pipes, and labeling

of the same to prevent confusion. Each of the smallest details was noted and given its place in the organization so that there would be no chance of any two conflicting. Finally, it was confidently felt that nothing had been overlooked and that the scheme was correct.

After the type of organization was planned it was necessary to determine the number of men required for each of the several operations. Since this had to be done accurately, scientific time studies were made. However, after the careful analysis that had already been completed, very few time studies were necessary; a very definite idea had been reached as to the number of men needed, and it but remained to check all plans.

The organization then appeared on paper as follows:

1 Second hand
1 Drug man
1 Floor man
1 Trucker
1 Color man
1 Cleaning man
7 Operators.

This arrangement would release,

1 Floor man
5 Helpers
1 Operator.

These transferred to other departments one at a time and the remainder paid a bonus of 20 per cent would call for the following results:

Increased machine capacity, 20 per cent
Reduction in working force, 35 per cent
Increase in pay to men, 20 per cent.

### Selling the Plan

As to this point, all plans were based entirely on observation. They were strictly plans of an official observer, having been developed in about a month's time on the job. But, of course, it is one thing to plan such changes and another to put them into effect with as little upset to the organization as possible. It was well realized that the greatest caution would be required to maintain the morale of the men.

The best feeling existed at the time, however, and skepticism had practically disappeared. Nothing definite had been discussed with the foreman because there had been nothing definite to offer. The men realized that the intention was to increase their pay, and that such increase would be based upon the amount of work produced. The older and more serious minded welcomed the idea. Only those who habitually soldiered were annoyed, but their attitude carried no weight with their fellow-men. It was felt that the proper attitude had been developed in the department, and that all plans were well laid.

Then one day the foreman was invited into the office for the purpose of discussing the work as laid out for the padders. The scheme was briefly outlined and he was told in as few words as possible the method of proposed procedure—that the machines would be equipped with two or three mechanical appliances in order that the operator could work independently of others, that an extra man would wash all tubs for the machine operators in order to increase running time, and that the operator would deliver his own patches for approval rather than sit down and wait for the helper to do it for him. He grasped the idea immediately and proceeded to ask questions concerning the minor details. The problem had been thoroughly worked out and he was given the answer to every question; but it was evident he had not been convinced. He had confidence in his organization and was reluctant to make any change. He was fearful that production would be curtailed rather than assisted, and that demoralization would result. To convince him that there would be no chance of disrupting the organization, he was told that the operation as planned would be worked out on one machine and later extended to the others.

### Installation

With this method of procedure agreed upon, one machine was selected. The operator was a husky Italian of middle age, father of seven children, and a worker rather independent of the rest. His term of service was not as long as most of the others, making it probable that he would be more adaptable. He was told that a bonus had been worked out for the job, but that before it could be paid alterations would be necessary both on the machine and the operation itself.

He accepted this with an open mind. It was known throughout the department why these investigations had been made, and that such work had been going on in another department where men had increased their pay 10 to 15 cents per hour. Therefore, if the opportunity were offered him, he would be anxious to try—"provided," he interposed, "it would not be necessary to work too hard."

The mechanical department started immediately to equip the machines according to instructions and drawings which had been prepared in advance. The illumination was improved, a better type of yardage clock installed, and the extra starting lever placed on the take-off side of the machine without having any noticeable effect upon the attitude of the employees. But when the one-man take-off neared completion, the various operators became appreciably annoyed. The man upon whose machine the work was in progress protested. One thousand yards of wet cloth were heavy and all that *two* men could handle—it was entirely out of the question for one man to handle a roll without assistance. He was good-naturedly humored and advised to wait and see how it worked.

Finally everything was in readiness. No change in methods had been requested, for it was evident that, first, the minds of the various men should be put at ease with reference to removing the rolls. The machine was supplied with dye solution and material, and started up as usual. At the completion of the first roll, all members of the department, including the foreman, curious as to the outcome, gathered around to see the result of the demonstration.

The designer of the apparatus, a member of the engineering department and a man of slight stature weighing about 140 pounds, stepped forward and grasped the center bar. With one hand he swung the roll from the machine and to the truck with no apparent effort. It was now easier for one man than it had been for two prior to the changes (see Figs. 3 and 4). The operator, a big 180-pound Italian, grinned sheepishly and returned to his work. For a long time afterward he would permit no one else to remove the roll, always insisting upon performing the operation himself.

The machine was now equipped to permit the elimination of idle man time. These contrivances were applied first, that the operators might have ample time to get used to them, and to some extent they were immediately adopted, although no requests had been made, it being necessary to do away with machine delays first. Accordingly, the machine delays were taken up in the following order:

1 All materials were classified and the correct speed for each class of goods determined. The starting box on each machine was then marked to show where the switch should be located for the proper speed, and the foreman was required to designate the class of all goods delivered.

2 The tub was washed by an extra man whose duty it was to

come immediately on signal from the operator when the last of the dye solution had been drawn.

3 Dye solution was prepared in advance and the helper's principal job was to see that it was in the tub before the operator was ready for it.

4 A patch drier was built. This was an elaborate affair with controls on heat, draft, and circulation permitting an exact duplication of conditions on the tenter frames. The foreman not only approved but became quite enthusiastic over its operation. The walk to and from the tenter frames was not only eliminated but the actual time of drying the patch was cut in half.

5 Miscellaneous delays were then approached through personal attention. The foreman was asked to require the drug man and floor men to give this machine the best of service. Each delay was noted and approached from its own particular angle, until there remained only the wage incentive to do the rest.

After devoting a few days to perfecting the service and reducing all machine delays to a minimum, it could be seen that the idle man time also was affected. The operator in the absence of his helper had learned not to wait. He had found it just as easy to start the roll, run a thousand yards, and remove it without assistance, sometimes even with the helper standing by and watching. However, when the patch was taken to be dried and then carried to the office for approval, the operator always found a nice, soft place to sit down and wait. The foreman had been asked to change this policy and require the operator to make this trip to the office for the purpose of getting closer contact and receiving all instructions at first hand. But the foreman considered it inadvisable in view of the fact that it had always been the method in the plant, and that he had never seen it done otherwise. Nevertheless there was no other solution, and in order to maintain equanimity it was necessary to

Fig. 3 Doffing a Roll Under Original Conditions, Two Men Required

approach the problem from another angle—that of dollars and cents.

### The Wage Incentive

The wage-incentive plan in effect in the plant was the regular Gantt task-and-bonus, allotting a definite time for a job. If accomplished in the time allowed, or less, the man's hourly rate was increased and he was paid for the full time allowed.

On the padders, this worked out simply. The task allowed was 0.2 hour per 1000 yards, and 0.2 hour for each patch. The man's hourly rate was 50 cents. A bonus of 20 per cent then amounted to 10 cents, giving a total wage of 60 cents per hour for accomplishing task.

With these figures it was simple to explain to the operator that he was to be paid 12 cents for each 1000-yard roll produced and 12 cents for each patch submitted, provided that he maintained an average of five rolls and patches per hour while on bonus.

It is always easier to explain it in some such easy way at the start, but invariably the average employee learns the regular method of calculating bonus in a short time.

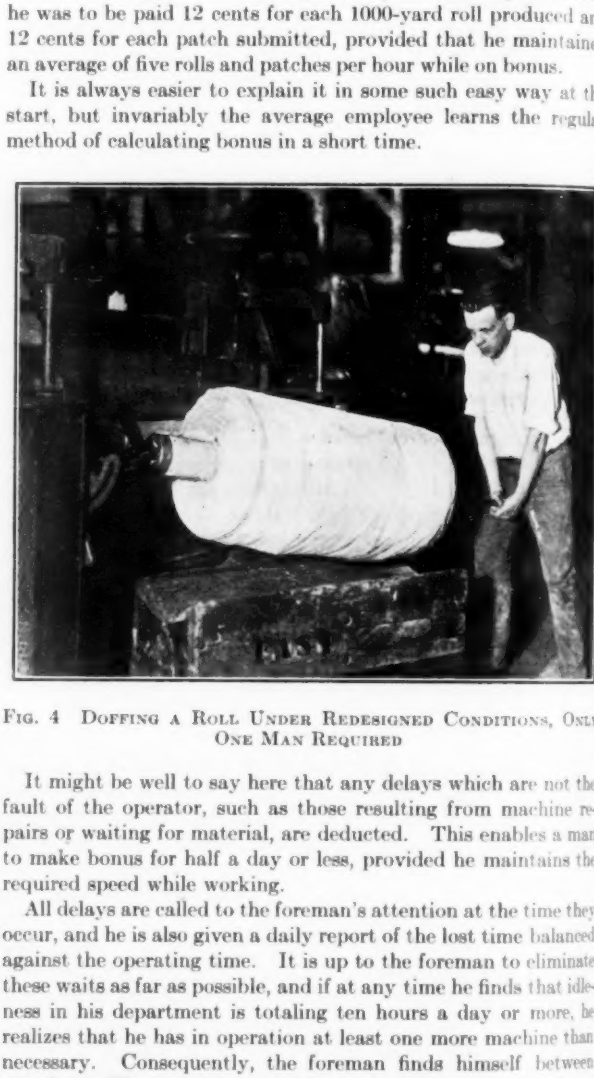

Fig. 4 Doffing a Roll Under Redesigned Conditions, Only One Man Required

It might be well to say here that any delays which are not the fault of the operator, such as those resulting from machine repairs or waiting for material, are deducted. This enables a man to make bonus for half a day or less, provided he maintains the required speed while working.

All delays are called to the foreman's attention at the time they occur, and he is also given a daily report of the lost time balanced against the operating time. It is up to the foreman to eliminate these waits as far as possible, and if at any time he finds that idleness in his department is totaling ten hours a day or more, he realizes that he has in operation at least one more machine than necessary. Consequently, the foreman finds himself between two fires. The operative, realizing that delays may cause him to lose bonus if no deduction is made, seeks credit for each wait. On the other hand, the foreman, subject to criticism from the management for excessive idleness, must maintain conditions to eliminate these waits.

In a department not working on such a plan, it is impossible to get a correct record of either machine- or man-hour delays.

### Starting the Task

On the day that the task was to be started, the operator on the experimental machine was approached before starting in the morning. He knew the general task-and-bonus plan, having talked with men from other departments who had been increasing their daily wage. He did not know how hard this particular task was, but he was anxious to receive more money and was willing to try. When told that he would be expected to dry his own patches and take them to the office for approval, he asked what the helper would be doing. It was explained that at present there was nothing, but since the operator was to receive the bonus, he should dry the patches. The result was not sur-

prising, for the handwriting on the wall was plain—in fact, rumors had been current for some time that some helpers would not be needed—the man parried and sidestepped. He argued that the operator had never dried the patch before; why, now, should he start it? It would add considerable work, and besides others would criticize. He was told that the management paid bonus on work done and it would be out of the question for him to expect bonus on idle time, but all to no avail. He seemed immovable, apparently affected by what others would think. The man was of the type that did not care for the opinions of others as a rule; but this seemed like asking too much and it was decided to lay off for a time. However, it was still believed that an entering wedge could be driven through the pocketbook, for he had a large family and needed all extra money possible to get. In order not to embarrass him and yet give him the chance to see that the task was fair and the bonus liberal, it was agreed that temporarily he need not dry the patch, but the time he waited for the helper to do it for him would be considered as idle time. Should he decide to carry the patch, he was assured that he would receive credit for it each time that he did.

The scheme worked as planned. At the start, he earned between 80 cents and a dollar a day extra. Soon he began experimenting, first to see how much he could earn, and then to see how easy he could work and still receive bonus. He dried a few patches and then a few more. Finally it dawned upon him that he was letting 20 or 25 cents a day slip through his fingers. Before two weeks had passed he was doing the task as laid out, and apparently without criticism from others. By this time several had asked for bonus, and one had gone so far as to dry all his patches to show willingness to do as requested.

The morale in the department was not at its best, but it was vastly improved and was considered satisfactory. Task and bonus had been applied on one machine for three weeks and had worked out to the satisfaction of one man. Others wanted it, so it was decided to go ahead with the work, and the mechanical department was given orders to equip all machines. As fast as they were put into shape the operators were offered bonus, and by the end of the week all machines were performing the task.

The work of improvement had gone surprisingly fast in view of the fact that more obstacles had been encountered than were expected. It had been planned to have the operation running smoothly by the time the peak load was reached, that production might not be limited; and this had practically been accomplished. Now, with the busy season at hand, all operators were working under the new conditions and the padders were not only producing the same number of yards as in the previous year with one less machine and without overtime, but upon an examination of reports for over a year previous it was found that a record week of production had been completed.

### Eliminating Excess Men

Although the bulk of the work had been finished, there was considerable yet to be done. Results so far had been obtained by keeping the machines in operation with little attention to idle man time. True, the operators had been given full-time jobs, but this had been accomplished by appropriating duties of the helpers, thus exaggerating their condition and leaving them but little to do. The two floor men also were finding it difficult to look busy, their principal work being to keep lots straight.

Accordingly one floor man and five helpers were transferred to other parts of the mill, retaining the senior floor man and three most likely helpers with duties apportioned as follows:

Floor man, to supply goods in proper order
Color man, to supply the dye solution
Trucker, to supply shells and deliver rolls for drying
Cleaning man, to wash tubs and assist others where possible.

For performing these duties satisfactorily, they were each to receive 15 per cent of the total bonus paid to the operators. If an operator lost bonus, the bonus paid to the service men automatically became proportionately smaller. This plan was used to develop a spirit of cooperation. Becoming vitally interested in the production of the machines, they not only did everything to help the operators, but helped each other as well.

### Breaking in a New Machine

Finally the new type of organization with the new distribution of labor was in operation as planned—not yet a perfect running machine but a well-designed one. All machines had to be broken into use gradually no matter how well put together, and this one did not prove the exception; it still needed the rough edges worn off. And in addition to being worn in, it had to be equipped with meters and gages in order to check the performance at all times and record bad conditions.

Although the organization was doing good work, each and every man, including the foreman, was on a job entirely different from the one at which he had served for years. Machine delays were entirely too frequent. The color man was frequently late in delivering the dye solution, and the floor man had difficulty at times in getting the next lot. They had not learned the best way of handling their work. Time would have improved this, but best results would never have been obtained without proper records and control.

To furnish these, a daily report was drawn up for the foreman, giving the record of each man as to work done, bonus earned, of idle time and why. When these reports first began to appear the foreman could not believe that such idleness was actually occurring, and made it a point to check each and every one. Finally becoming convinced that his department was totaling more than ten hours a day of machine idleness, he realized that he was operating with more machines than were necessary. On short notice he cut off one machine and made a drive on the service men to eliminate all delays.

### Results

Here the department is left with the feeling that it is in first-class condition, although not a finished product, for a year's operation at least will be required before conditions and operations are running as smoothly as desired. And always the engineer will receive the same daily report which the foreman receives, that he may know if conditions are improving or retrograding.

Here, a brief survey of records is opportune in order to determine, by comparing data obtained prior to the change with that of the new organization, if results have come up to expectations.

| | | |
|---|---|---|
| Average daily production per machine: | Prior | 20,100 yards |
| | Present | 27,500 yards |
| | Increase | 36 per cent |
| Average daily wage per man: | Prior | $4.55 |
| | Present | $5.70 |
| | Increase | 25 per cent |
| Average unit labor cost: | Prior | $0.072 |
| | Present | $0.052 |
| | Decrease | $27\frac{1}{2}$ per cent |

Annual reduction in labor cost per 100,000,000 yards—$20,000.

Also, it would be interesting to note conditions pertinent to the quality of performance. Maintenance of quality is strictly a function of the foreman, and the following conditions afford him greater opportunities to this end:

1 The best men were retained when the excess help was transferred

2 Competitive concerns must raise their bids considerably in order to entice the skilled help
3 A higher grade of employee is being obtained because of the higher wage
4 Operators watch their work more closely in order to avoid difficulties
5 There is less distraction in the absence of men with nothing to do.

The data presented here to show results in connection with quantity and quality production, together with increased capacity and lowered costs, are very conservative. As time goes by and wrinkles are further smoothed out, the figures will appear even more favorable.

### Conclusion

The problem has not been that of a dye house alone, but is typical of what occurs in many departments in every finishing plant. However, an organization of this type, where the duties of its various members are functional and its success depends strictly upon cooperation, seemed particularly applicable in this case. It is not recommended for all dyeing departments, for conditions vary widely throughout the textile industry, but an average set of conditions found in an average department has been cited.

But when conditions are cramped, and flow of work is throttled, and costs are high, or capacity is limited, unless the department has been thoroughly analyzed by one who has the time and experience, there is every reason to believe the company is throwing away money. If the stage has been reached where the purchase of new equipment or more floor space seems necessary, it is strongly recommended that a scientific investigation be made before laying out the money.

## Discussion

T. R. Read.[2] We recognize the truth of what we have just heard, having put a bonus system in three of our branches on padders, and I would like to say that there is hardly an operation in a finishing plant that does not offer an almost equally interesting story.

We have of course found differences of opinion as to the best method of handling cloth through the padders and also as to the best means of taking patches, and while we have arrived at definite opinion as to the most efficient way of handling these, nevertheless we sometimes have to concede some of the smaller points for the sake of not interfering with the boss dyer's own ideal of best quality.

I can see that our story is very similar to the author's. I think the only difference is one of cost (a very slight difference) and a different wage-incentive system. We are using a modified Gantt bonus system.

### Author's Closure

Gerald Chapin of the Pacific Mills, Lawrence, Mass., asked the size of the runs on which was obtained the figure showing an average of 27,500 yd. a day for each machine. The actual average is a little higher than 2000 yd. per shade, probably running nearer to 2200 yd. A very important part of the same question is, how many strike-offs does the operator take before hitting a match to the shade? Figures show about 50 per cent more strike-offs than shades. In other words, this means that every second shade the foreman hits a match at the first attempt. Of course what brings up the average is the running of samples, etc., which require more strike-offs than the regular runs. Here is some data which may give more clearly the possible production under actual conditions. I do not know that these figures are of a record day, but they are of a very good day and will show what these particular machines are doing and what may be expected from machines working under bonus conditions. The average per machine for the day was 35,500 yd., with 13 shades and 20 strike-offs per machine, netting the operators an average bonus of $1.46. This shows an average of 2700 yd. per shade, with approximately 54 per cent more strike-offs than shades.

J. D. Robertson, Mount Hope Finishing Co., North Dighton, Mass., asked what percentage of time the machines were actually running, that is, the percentage of running time that the cloth was actually passing through the machine. Mr. Robertson had been trying some service recorders like those in use on automobile trucks and found on the padders that he was getting an average of 60 per cent running time. Answering Mr. Robertson, without any specific data I should say about 60 per cent is correct, or a little more than the time spent in taking strike-offs. This can be figured quite accurately for any particular time knowing the number of patches taken and the number of yards delivered. The time permitted by the task for taking a strike-off is equal to the time for running 1000 yd. Upon the day just mentioned seven hours were allowed for running 35,000 yd. and four hours for taking 20 patches. This shows a running time of seven-elevenths of a day's work, equivalent to a little more than 63 per cent.

In reference to the patch drier, this was developed carefully and thoroughly, for the foreman was very particular about the treatment his patches received. He would not consider the ordinary steam-heated cylinder because of the possibility of the metal affecting the shade. Even if the patch was placed between two pieces of cloth to prevent it from coming into contact with the metal, the heat seemed excessive and fear was expressed that the correct shade would not be obtained. So the patch drier was built to duplicate conditions on the frames. This was a well-insulated box containing eight drawers, one for each padder. Under the drawers was a steam coil fed by live steam which could be throttled to obtain proper heating and exhausting into a steam trap. A Western Electric fan with three speeds enabled the control of air circulated through the steam coils and down over the patches which were placed into the drawers with wire-net bottoms. A small damper at the bottom of the box to allow fresh air to enter and another at the top to permit stale air to escape enabled the foreman to regulate the moisture content until he was satisfied that conditions were maintained as constant and satisfactory. Better results were thus obtained than previously when drying patches at the frames. Formerly when the operator took the patch for drying he did not carry it into the hot house, but held it close to the opening at the entering end to be dried by the air thus escaping. This air was not only moisture-laden, but had lost considerable heat.

Answering the question of our chairman, Henry M. Burke, we did not use pumps to return the dye solution to the tubs. Pumps used for this purpose make a good labor-saving device, but under this particular condition would not have resulted in time saving. There was never more than a bucket and a half or two buckets of dye solution in the machine for taking a strike-off. If the patch was not accepted, it was necessary to wait for the color man to supply the additional dyestuff, requiring approximately a minute and a half. During this interim the operator had ample time to drain the machine and return the solution to the tub. He also had time to sew a new leader to the patch, preparatory for the next strike-off. Pumps would not affect the efficiency of the operation.

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# The Value of Water in Textile Mills for Purposes Other Than Water Power

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*The value of water for industrial purposes—process water, water for condensers, etc.—is an item which must be included in the valuation of many industrial properties. The object of the paper is not so much to establish definite values as to discuss methods which will assist in arriving at definite figures for any particular case. In his analysis the author discusses four cases and various conditions which affect them: (1) Where water is purchased from a water-power company; (2) where it is taken from a stream on which the user owns the riparian rights; (3) where it is obtained from driven wells; and (4) where it is purchased from a town or city supply. An example of the use of the basic figures arrived at by the author is given for the case of a colored woolen mill.*

THE value of water for industrial purposes is an item which must be included in the valuations of many industrial properties.

Many industries are dependent upon an ample supply for their processes, and when takings of watershed for public water supplies are made, enough suitable water must be left to carry on the processes requiring its use. If this is not done, it may be necessary to condemn the whole property.

The author has not seen any printed matter on this subject, and, with the hope of bringing out some valuable information, is presenting some views on the subject which may establish a starting point at least for some logical conclusions.

The object of this paper is not to establish definite values so much as to discuss methods which will assist in arriving at definite figures representing or indicating values in any particular case.

The figures given are approximate only, and cannot be expected to apply to every case. If the paper serves to bring out discussion on this subject, its object will have been partially accomplished.

The determination of the value of water for power can be made with some degree of accuracy, but the determination of the value of water, or the right to use water for the various processes in manufacturing, and for other purposes, as condensing, and for what might be called domestic uses in the mill, is difficult, because of the wide range of the cost of procuring a suitable supply and the varying conditions of its uses.

The value of anything is not necessarily measured by what it costs to obtain it, but by what it would cost to obtain the same or equivalent results in a reasonable and practicable way.

Thus the value of a water power can be determined by comparing the cost of producing and delivering power to the place where it is used with the cost of producing and delivering the same amount of equally reliable power in some other way, as by steam power, internal-combustion engines, or by purchased electric current, taking into account in each case all the elements of cost.

There is no substitute at present for water for manufacturing purposes, and therefore its value cannot be determined by the substitution of some other thing which would produce the same results.

There have been sales of properties in which one element of value is the possibility of using water for manufacturing purposes, but it is impossible to segregate the value of this element from all other elements of value.

The value of water, or the right to draw water, depends largely upon the use to which it is to be put, and the physical requirements for preparing it for such use.

In a manufacturing plant there are usually the following uses, in addition to the use of water for water power:

1 Water for manufacturing purposes, sometimes called process water
2 Water for condensing when steam power is produced and where there is only a partial or no use for low-pressure steam for heating or in the manufacturing processes
3 Water for sanitary or domestic purposes
4 Water for drinking.

As a usual thing, drinking water is obtained from a different source from that which supplies the water for the other uses, and as the amount of water required for sanitary purposes is relatively small compared with amount of process and condensing water, these two uses will be given no further consideration here.

### Water for Manufacturing Purposes

Occasionally a concern has an ample supply of water which is particularly adapted in softness and other qualities to the work to be done. In such a case the water for manufacturing may have a special value.

Such a condition may occur in a small stream which is unpolluted by any other manufacturing plant above it on the stream, and which can be reservoired, or on any stream where the pollution or hardness is so small as not to be harmful.

In a few instances there are reservoirs furnishing by gravity an ample supply of good water which comes from a source independent of the main stream.

The cost of procuring such a supply would usually be the cost of creating the reservoir by the purchase of some cheap land and the construction of a dam, and of the piping system to the mill. The cost of such plants will vary considerably.

There are some cases in which the process water is supplied from driven or dug wells. The cost of such wells, and the amount of water available, will vary enormously. With such an arrangement there is the cost of pumping.

These physical structures add to the value of a plant whatever they cost, less depreciation, up to a point where the fixed and operating charges become equal to the cost of obtaining water in some other ordinary and customary way. Above that point there is no further value to be added for physical structures and nothing left for the value of the water itself, just as in the case of water for power, where, when the cost of physical structures reaches a certain amount, anything above that amount is of no value, and there is nothing left for the value of the privilege.

In manufacturing cities where the water is controlled by a separate water-power company, water is sold, or leased, for power and other purposes, and in such cases the sale price is some measure of the value of the water.

Most of the indentures for water were made many years ago, and were largely made for water for power and do not represent

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present-day values of water for manufacturing purposes. More recent leases are some indication of present values. At least they show what some manufacturers are paying for this service.

In the great majority of cases the mill owns the riparian rights on a stream and takes its water from the same pond from which water is drawn for power. If the level of the water above the dam is of sufficient elevation, the water can be drawn by gravity into the various machines in which it is used. If the water level is not sufficiently high, the water must be pumped.

Most of the earlier textile mills, especially the woolen mills, were located in New England on rivers, the waters of which were unpolluted and were suitable for manufacturing purposes.

As the number of mills and communities have increased, these rivers have become more or less polluted, and the water from some of them must be treated before it can be used. The value of the supply under these conditions is relatively less than it was formerly. In some cases the supply has been abandoned, and water purchased. This may be a burden which tends to decrease the value of the property.

The use of water from city or town supplies at domestic rates would be prohibitive in most cases, especially if the amount used is large.

As the number of new and good supplies available has diminished, the value of the remaining good supplies has increased.

The value of the right to draw and use water for manufacturing purposes is not necessarily measured by the cost of getting it. It can be measured by the cost of getting it in some reasonable and common method. As in the case of water power, the less the physical structures cost to build and maintain, the more valuable is the privilege or right to draw. There is a reasonable sum that can be spent for the privilege and plant so that the concern will not be handicapped in competition with other mills.

For example, supposing the water is obtained from deep wells at great relative cost, nothing could be added to the value of the site for this when compared with the value of sites where the cost of getting water would be comparatively low; or, if the water is taken from the town or city supply at high rates, no value can be added to the site for this reason; but on the other hand there may be something to be deducted for this handicap, in the same way that a location requiring excessive haulage will involve a constant source of extra expense which tends to reduce the value of the site.

The cost of obtaining water for manufacturing purposes may be an indication of its value under any of the following conditions:

1 When the water is purchased from a water-power company. This gives the most definite indication and applies to many cases of concerns engaged in similar businesses.

2 When the water is taken from a stream by the owner of the property who also owns the riparian rights, accomplished by the building of the necessary structures and appliances to make use of the water. This is the most common case, and is usually the least expensive method of obtaining the water.

3 When the water is obtained from wells which usually involves large expenditures for construction and operation. This is not a common method and usually results in a higher cost of water and, therefore, a lower additional value for the site than with (1) or (2).

4 When water must be purchased from a public or privately owned water supply principally used for some other purpose, such as the supply for a town or city. The costs in this case are usually prohibitive for plants requiring large amounts of water.

### Water Obtained From Water-Power Companies

Water is sold or leased by water-power companies as in Lawrence, Lowell, and Holyoke, but even in these places the charges are not uniform. Some of the sales of water for manufacturing and condensing made prior to the period of increased cost of the last few years, which are not confused with water for power, indicate that a fair charge, at the time, for such water was about $1200 a year a mill power, a mill power being equivalent to about 8,000,000 gal. in 10 hours.

This charge was before the increase in cost of about everything and the decreased value of the dollar, and under present conditions may be equivalent to about $3000 a year.

In a more recent agreement the price for 8,000,000 gal. a day was fixed as follows:

| | | |
|---|---|---|
| First 5,000,000 gal. at $3.00 per million | = | $15.00 |
| Next 3,000,000 gal. at $2.00 per million | = | 6.00 |
| | | $21.00 |

$21 × 300 days = $6300 a year for 8,000,000 gal. a day, or about $800 a year for a million gallons a day.

In these cases the water-power companies own, control, and operate the dam and canals up to the intake for the water into the mill, the mill having only the local distribution system to install and maintain. The mill may also have filter and pumping plants for a portion, or all, of the water. This water is usually supplied under some head, and a good deal of it may be used without pumping.

### Water Taken From a River

The most common method is where the water is taken from a river on which the user owns the riparian rights, and which is drawn by gravity, or where it is pumped to tanks and used from the tanks by gravity.

In many of these cases water is furnished under some head and much of it could be used without pumping. The conditions are generally not much different from those when water is taken from a water-power company, except that the right to the use of the water is a part of the riparian rights of the owner of the property, the water itself does not have to be paid for, and the dam, canals, or other channels are owned and maintained by the mill itself. Usually the development is made primarily for water power, and the water for manufacturing purposes taken from the pond created for power purposes.

The cost of obtaining water in this way is relatively small in most cases. Its value would be no more than water of similar quality supplied under similar conditions in the large manufacturing centers by the water-power companies.

### Driven Wells

The cost of driven wells will vary enormously. With an adequate supply of water at a short distance below the surface, the cost might be such as to compare fairly with the cost of obtaining water from a river or from a water-power company. With deep-driven wells the cost would be so high as to be a burden on the mill in comparison with the other methods of obtaining water.

A recent installation for 2,000,000 gal. a day cost $48,560. If this plant were extended to a capacity of 8,000,000 gal., the installation cost would be not over $150,000 or about $19,000 per million gallons per day.

### Purchase of Town or City Water

It is not the usual custom to encourage the use of water from town or city supplies by manufacturing plants using large quantities of water. Most towns and cities would be unable to supply the amount required by large mills.

The town or city must charge enough for this water, if it does sell it, to cover the cost of obtaining, and usually of pumping, storing, and distributing the water, and for such treatment

as may be given to it. The water would be delivered at a greater head than is required if the water is pumped from the river into tanks. All of these charges would make a price for the water that would probably be prohibitive. If, however, there should be one or more acceptable establishments requiring considerable amounts of water in a town, and if the supply is ample, the charge should be the minimum possible amount, even perhaps at less than cost, in order to encourage the establishments to remain there for the general good of the community.

### Summary of Cost

1—*Water Obtained From Water-Power Companies.* A rental of \$3000 per year for the right to draw 8,000,000 gal. a day is equal to \$375 a year per million gallons a day.

As the water-power company maintains the dam and water channels, the user has only the distribution system on his property to maintain, the expense of which is common to all users. The yearly cost might then be capitalized at interest charges only, say, 6 per cent.

The amount \$375 capitalized at 6 per cent is equal to about \$6000. This represents the capital value of the right to draw 1,000,000 gal. a day for the working days of the year, and is low in comparison with a more recent lease.

Based on the agreement of \$21 a day for 8,000,000 gal., which is equivalent to about \$800 a year for a million gallons a day, we have \$800 capitalized at 6 per cent, equal to about \$13,000 for the value of the right to draw one million gallon per day.

At a rate of \$3 a day per million gallons this would be \$15,000.

2—*Water Obtained From Owner's Pond.* A million gallons in ten hours = 3.7 cu. ft. per sec. With an assumed head of 30 ft., this would produce about 10 hp. This might be worth for power \$20 a year per hp., or about \$200 a year in all. This amount capitalized at 6 per cent equals \$3333.

The value for manufacturing purposes is greater than for power, and therefore this figure is low.

3—*Water From Driven Wells.* In one case we have an installation cost of \$19,000 per million gallons a day. This is high in comparison with the other methods.

*Arbitrary Assumption.* We have now figured a range from \$6000 to \$19,000 as the capital value per million gallons a day. It might be safe to set up an arbitrary base value of \$10,000 from which to start.

It might also be assumed as a general proposition that one-third of the water, which is the amount used for the final process work, requires pumping and filtering, a supply which requires no treatment or pumping is worth considerably more than the base of \$10,000 per million gallons a day.

### Effect on Value by Reason of Not Being Obliged to Pump

If all of the water is pumped, with a total lift and head of 30 ft., the cost of pumping will be about 0.5 cent per 1000 gal., or \$5 per million gallons a day, or \$1500 a year, which capitalized at 6 per cent equals \$25,000.

One-third of this would be \$500 a year per million gallons a day. It would take a capital sum of roughly \$8000 at 6 per cent to pay for this pumping, and a supply not requiring any pumping would be worth \$10,000 + 8000 = \$18,000 per million gallons per day.

### Effect on Value by Reason of Not Being Obliged to Filter

If all the water were filtered, and with sufficient storage tanks, it would ordinarily cost about 1.5 cents per 1000 gallons, or \$15 per million gallons a day, or \$4500 a year of 300 days, and for one-third filtered, \$1500 a year. This figure would vary considerably with different water supplies.

The amount \$1500 capitalized at 6 per cent equals \$25,000, and a supply not requiring any filtering or pumping would be worth \$10,000 + 8000 + 25,000 = \$43,000 per million gallons per day.

If the water is used in a plant requiring more than one-third to be pure or more than one-third to be at high pressure, and filtering and pumping are eliminated by the nature of the supply, then the value of the supply would be greater than the above.

The supply which is of the greatest value per unit of amount is one supplying soft and pure water which does not require treatment for softening or filtering, and which is supplied by gravity and does not require to be pumped.

If it is conceivable that all the water must be pure and that all of it must be delivered under pressure, and if the natural conditions will insure these, then the value would be \$10,000 + 25,000 + 75,000 = \$110,000, which is the maximum limit for a supply of one million gallons per day. This limit would not be reached ordinarily. We should say that \$50,000 might be set as the highest value per million gallons a day for ordinary uses.

We have now established tentative limits of \$10,000 for a million gallons a day for a majority of cases, and \$50,000 for exceptional supplies.

It must not be assumed that the foregoing figures are applicable to any particular case, but a method has been indicated by which an estimate can be made for any given general locality of the approximate value of the water for manufacturing purposes.

### Effect of Changes in Conditions

In the earlier days mills were located on streams which would furnish an ample supply of good water for manufacturing purposes. As time has gone on, the supply may have been reduced by takings or may have become inadequate or have become polluted.

If a manufacturing plant has grown so that its water supply has become inadequate or unsuitable, and the plant cannot be moved to a location where the conditions of water supply are favorable, and must be put to unusual expense in obtaining a suitable supply, any excessive capital outlay for obtaining the supply does not add to the value of the property, but in fact may become a burden upon the property and tend to reduce its value.

This additional or unusual expense may have been incurred by the cost of building dams and creating reservoirs; by excessive cost of driven wells; where the water has become polluted, thus requiring excessive cost for purification; or where water must be taken from a city or town supply at high rates.

The base value can be established by a consideration of the cost of the supply to a large majority of establishments which are on a competitive basis with the particular establishment under consideration. A supply with unusual beneficial characteristics will be worth more than the base value. A supply which costs an excessive amount for obtaining and preparing for final use may not add anything to the value of a plant, but may on the other hand cause the total value of the plant to be less than it would be with an economical water supply.

### Example of the Application of the Foregoing Figures

A colored woolen mill, running one shift, will use about 30,000 gal. of fairly good water a day per set of cards when there is a plentiful supply, but satisfactory work can be done with a less amount if necessary.

*a* For the majority of cases where water is taken from a water-power company or from the owner's mill pond, \$10,000 per 1,000,000 gal. a day is a fair base value to assume. $\$10,000 \times 30,000 \div 1,000,000 = \$300$ a set.

*b* Assuming that in a woolen mill one-third of the total amount must ordinarily be pumped, a supply requiring no pumping would be worth $\$18,000 \times 30,000 \div 1,000,000 = \$540$ per set.

*c* Assuming that in a woolen mill one-third of the total amount must ordinarily be pumped and filtered, a supply requiring no pumping or filtering would be worth \$43,000 × 30,000 ÷ 1,000,000 = \$1290 per set.

*d* Based on the more recent agreement mentioned in an earlier paragraph, and using the charge of \$3 per day per million gallons, we should arrive at a value of \$450 per set.

### Water for Condensing

In some plants water is required for condensing as well as for manufacturing, and in some for condensing only. The use for condensing is diminishing in mills, as many of the newer mills are run by purchased electric current and some of the older ones are not replacing the steam plants as they become worn out, but are purchasing current for additional power requirements.

This water does not require treatment for hardness or impurity. When a plant is located at tide water, salt water may be used.

In the manufacturing cities where there are water-power companies, this water is furnished at the same rates as for water power. In mills owning their own water power, the water is usually taken from the mill pond which also supplies water for power.

In some mills the condensing water is used after passing through the condensers for process water, thus reducing the total amount of water required for both purposes and utilizing the waste heat of the power plant.

The value of water for condensing depends upon the adequacy of the supply, the ease with which it can be obtained, the cost of fuel, and the amount of the waste heat from the engine or turbine which can be used for manufacturing purposes. Water for condensing purposes cannot have any value to a plant where the cost of power generated by a condensing plant would be higher than the cost of obtaining the power by some other acceptable method.

Water has no value as power until it is harnessed and is producing power. The potential possibilities for the development of power add value to the riparian rights whenever it becomes economical to develop these possibilities, and also to the land contiguous to the stream.

Water for condensing has no value for that purpose until it is so used, but when it becomes necessary or economical to develop steam power in a certain locality there is added potential value to land so situated that water can easily be obtained for condensing purposes, and such land becomes of more value than other adjacent land where water is not available or is available only at great expense.

Three methods of estimating the increase in value suggest themselves:

1—Its value for condensing can be measured by the net saving produced by its use, taking into account operating and fixed charges. In a manufacturing plant the amount required will depend upon the amount of exhaust steam which can be used in the processes and for heating.

If the majority of plants doing similar work could purchase or obtain water at a moderate cost, other plants in competition with these would be at a disadvantage if it costs them more for condensing water. Before they suffered an actual loss in power production, however, they could pay up to a sum which would represent the saving due to condensing over non-condensing, unless there was a cheaper substitute power available.

The net saving of condensing over non-condensing operation, with engines of 500 hp. and upward, running 10 hours a day with coal at \$6 a long ton, is approximately \$2 a year per hp., of engine load, and for a plant running straight condensing the total yearly saving would be roughly \$2 per hp., with no allowance being made for fixed and operating cost of the plant necessary to get the water to and away from the condensers.

Assuming for the purpose of illustration that it cost \$3 per hp. for the physical structures required to get the water to and from the condensers, and the fixed and operating charges at 50 cents a year per hp., the net saving would be \$1.50 per hp. a year. This capitalized at 10 per cent equals \$15, which represents the capitalized value per horsepower.

Ten per cent capitalization is used here, whereas 6 per cent was used in connection with the value of water for manufacturing purposes. With the increased application of electric current for power there is less use for water for condensing, and the future possibilities for cost of power are subject to a fluctuation of value, whereas good water for manufacturing purposes is becoming scarcer and its use cannot be done away with.

If it takes 60 gal. per hour per hp. for condensing, or 600 gal. per day of 10 hours, the capitalized value of 600 gal. a day would be \$15. This is the maximum value on this basis.

At this rate the value for 1,000,000 gal. a day for a year would be \$15 × 1,000,000 ÷ 600 = \$25,000.

If the exhaust can be used in part or in whole, the value per horsepower would be reduced, but the value per 1,000,000 gal. would remain the same. With varying percentages of exhaust use the value per horsepower would be as follows:

| Per cent of exhaust use | Value per hp. |
|---|---|
| 25 | \$11.25 |
| 50 | 7.50 |
| 75 | 3.75 |
| 100 | 0.00 |

In most colored mills at least as much as 50 per cent, and often as much as 75 per cent, of the exhaust would be used and the value per horsepower would then be \$7.50 and \$3.75, respectively.

For the purpose of illustration, we shall assume that 50 per cent of the exhaust will be used. On this basis the value of water for condensing purposes per set of woolen cards would be 40 hp. × \$7.50 = \$300. If all waste heat of the prime mover can be absorbed in the manufacturing process, the value would be nothing.

If the water can be used for manufacturing purposes after passing through the condenser, a double value cannot be given to it. It would be worth the maximum value of its use for either process purposes or for condensing, and if a portion is used for each purpose the sum of the maximum value for each will represent its value.

Steam turbines under fairly normal conditions require about 120 gal. per kw-hr., or 90 gal. per equivalent hp.

As non-condensing turbines are very uneconomical unless the exhaust steam can be used for manufacturing purposes, it would not be advisable to run non-condensing when there is a scarcity of water. In such a case it would be necessary to install cooling devices for the condensing water or to obtain the power by some other method. The value of condensing water for turbines should not be determined in the manner as indicated above for engines, but might be estimated as indicated below or by comparing the cost of power from condensing turbines with that of purchased current or some other manner which would give reasonable results.

2—Another measure of the value of the opportunity to use the water for condensing is the difference in the cost of equipment and of the operations necessary to deliver the water to the condensers as against some other common way of providing the water as by cooling towers or ponds, taking into account also the relative efficiencies of these methods.

Assume for example that the cost of cooling towers and accompanying apparatus is roughly \$10 a kilowatt.

| | |
|---|---|
| The fixed charges on $10 at 15 per cent a year would be | $1.50 |
| The yearly cost of operation per kilowatt, allowing for lower vacuum, is approximately | 3.25 |
| Cost of make-up water | 0.75 |
| Total cost per year with cooling tower | $5.50 |

Yearly cost with an abundant water supply:

(Cost of intake and piping, pumps, or whatever plant is required, say, $5 per kw.)

| | |
|---|---|
| Fixed charges on $5 at 15 per cent | $0.75 |
| Yearly cost of operation | 1.50 |
| Total | $2.25 |
| Net yearly saving, $5.50 — $2.25 = | $3.25 |

$3.25 capitalized at 10 per cent = $32.50 per kw.
= $24.50 per hp., approx.

Gallons per kilowatt = 120 per hour.

120 gal. × 10 hr. = 1200 gal. a day per kw.

$$\$32.50 \times \frac{1{,}000{,}000}{1200} = \$27{,}000 \text{ per } 1{,}000{,}000 \text{ gal. a day.}$$

Per set of woolen cards requiring about 30 kw.: $32.50 × 30 = $975, say, $1000, when running straight condensing, or $500 when 50 per cent of the steam is extracted and used for manufacturing purposes.

The extra investment in a cooling-tower installation may sometime be offset by the cost of condensing-water intakes, screens, and tunnels, and discharge trenches or canals where water is taken from so-called natural sources. The vacuum obtained when using cooling towers or ponds is rarely ever as good as that obtained where the supply of water is ample.

3—One other method would be by comparison with the charge for such water in communities where it is sold or leased by water-power companies.

Based on charges for water by companies controlling water for manufacturing in manufacturing cities, it would be worth for condensing the same as for manufacturing purposes. We have previously in the paper set up a base of $10,000 per million gallons a day.

600 gal. per hp. a day × 40 hp. = 24,000 gal. a day.

$$\$10{,}000 \times \frac{24{,}000}{1{,}000{,}000} = \$240$$ per set of cards when running full condensing, or $120 when half the exhaust is used.

In most cases this water does not require pumping. By reason of not requiring pumping, the value is increased by $1500, which, capitalized at 10 per cent equals $15,000, making a total of $25,000 per million gallons. This figure would make the value $600 per set of cards for straight condensing and $300 when half the exhaust is used.

### Base Value

In the discussion of the value for manufacturing purposes, we established a base value of $10,000 per million gallons a day. This same figure might be established for water for condensing, at least for manufacturing concerns which are engaged in competition with others located in manufacturing cities where water is sold at the assumed rates.

Compared with the above base figure, an unlimited supply of water would not be of any greater value unless it could be supplied more easily than the water purchased as described above. It would be of less value if the physical structures required to convey it to the condensers cost more and if the water had to be pumped.

### Application to a Woolen Mill

1—Based on the difference in cost of running engines condensing and non-condensing:

| Proportion of steam condensed | Per million gal. a day | Per kw. | Per hp. | Per set of cards |
|---|---|---|---|---|
| All | $25,000 | ... | $15.00 | $600 |
| Half | 25,000 | ... | 7.50 | 300 |

2—Compared with cooling towers and cooling ponds:

| | | | | |
|---|---|---|---|---|
| All | $27,000 | $32.50 | $24.50 | $980 |
| Half | 27,000 | 16.25 | 12.25 | 490 |

3—Compared with sale of water in manufacturing cities:

| | | | | |
|---|---|---|---|---|
| All | $25,000 | ... | $15.00 | $600 |
| Half | 25,000 | ... | 30.00 | 300 |

### Some Tentative Conclusions

1—Base value of water for condensing per million gallons a day ........ $10,000

Under especially good conditions this figure may be as high as ........ $25,000

2—Base value for ordinary colored woolen mills:

| | |
|---|---|
| Value of process water per set of cards | $300 to $450 |
| Additional value of condensing water per set of cards | $300 |
| Lowest value for both purposes, fairly good water | $600 to $750 |

3—As these values may easily vary, a figure might be used in valuation work for all water needed per set of woolen cards in a mill driven by its own power plant, of $700.

4—For special advantageous conditions, the figures would be higher as indicated in the text.

5—The value may be determined by subtracting from its maximum theoretical value the capitalized cost of getting the water to and from the place where it is used and in a proper condition for use.

6—The capitalized cost of obtaining water may be much more than what it would be under ordinary fair conditions, but when it is more and there is no alternative, it puts a burden on the plant and adds nothing to its market value. It may even cause the value to be diminished.

## Discussion

Harrison P. Eddy.[2] The author has presented a very important subject, but one which has not been, I believe, as fully appreciated during the past generation as it is now and as it will be in the future. The author's discussion is so nearly in accord with my own views that I will add only one point which he evidently has intentionally omitted, but which in my judgment is a real factor in establishing the value of water and the value of a plant or plant site. This factor is the difficulty of getting rid of the water after you have used it in the processing. Thirty years ago the disposal of industrial wastes was rarely a serious problem, although the thought comes of the case of Parker versus American Woolen Company, dating back fully 30 years and perhaps more, which is the foundation as I understand it of the decisions which have followed in Massachusetts since that time.

What will be required for the disposal of industrial wastes is exceedingly problematical. It depends upon the population downstream for one thing and very largely on the public sentiment for another. Conditions are complained of today which even five or ten years ago were taken by the public as a matter of course.

There is the further problem connected with the disposal of industrial wastes and that is their effect upon the water used for process purposes farther downstream.

As regards the value of water for dilution purposes there is, first, its use for the disposal of sewage. Ordinarily this is not a very serious problem for industrial establishments, although there is always a small amount. It has been determined, as a very rough rule, that 3 to 5 c.f.s. of water is the quantity required for the satisfactory dilution of the sewage of 1000 persons tribu-

[2] Partner, Metcalf & Eddy, Boston, Mass. Mem. A.S.M.E.

tary to a stream. The estimated cost of sewage treatment today on a relatively complete scale suitable to discharge into a small stream is about $1200 per 1000 persons per year, or capitalized at 6 per cent, about $20,000. The value of diluting water, then, on the basis of 3 c.f.s. per 1000 people is $10,400 per 1,000,000 gal. In other words, if 3 c.f.s. per 1000 population can be drawn and will accomplish the same purpose as the treatment I have suggested, then you can afford to pay $10,400 per 1,000,000 gal., or taking the higher figure of 5 c.f.s., the value drops to $6250 per 1,000,000 gal.

Another example, and that is one that applies to tannery wastes which are worse to treat than textile wastes. At a certain tannery which has a large wool-scouring plant the treatment of industrial wastes amounts to $179 per 1,000,000 gal. If the treatment is eliminated and sufficient diluting water is furnished, then for dilution 50 parts of water would be required for 1 part of industrial waste.

The value of this water for diluting factory waste would be $179 divided by 50 or $3.58 per 1,000,000 gal. daily, equivalent to $1300 per year. Capitalized at 6 per cent the diluting water would be worth about $21,600 per 1,000,000 gal.

The net result of these computations indicates that, for diluting municipal sewage, water has a value somewhere in the neighborhood of $10,000 per 1,000,000 gal., at least for illustrative purposes, and for dilution of industrial wastes the value may be as high as $21,000 to $22,000.

Edwin H. Marble.[3] I would like to ask if either Mr. Main or Mr. Eddy has any figures in regard to the adjustment of the disposal of the water which was claimed to be polluting the stream just below Passaic. Two or three plants were abandoned, and there were figures placed as to what the valuation was and what they should be reimbursed for their plants in that matter. It was a very serious adjustment, they claiming that three plants, two small ones and one large-sized one, were polluting the river, and there was a valuation as to what the river was worth in the first place and the damage caused by polluting it with dyestuffs, etc., and I have heard that the fish were all killed.

If my memory serves me right, the plants made the claim that their plants had an additional worth because they had a water supply, and the City of Passaic offset that claim by the damage done to the water by the waste or by the dye-house waste, and there was a valuation set on the water power and the privileges, and also they tried to set up a counter-claim. The case was tried before three engineers. This is an engineering problem that I have never heard thoroughly discussed.

William Heffernan.[4] I am right in that community where the Passaic River is polluted. It seems the pollution of the river dates back some years, and the Standard Bleachery, where I am located, contributed to the damage done to the river. At our particular plant we installed about three years ago, although I was not there at the time, a sewage system for taking care of the waste before it goes into the river. A large trunk sewer was started about ten or twelve years ago, I have been told, and it extends from Newark up to Paterson. It is about 4 ft. in diameter at Paterson at present, and when it reaches Passaic it is about 12 ft. in diameter, and continues on until it connects with the disposal plant of the Passaic Valley Sewage Commission at Newark.

In connection with the mills there has been great agitation going on in this district for some time, and the mills are doing all they can in cooperating with the Passaic Valley Sewage Commission in order to clean up the river. At the Standard Bleachery Company, where we have a system for treating our waste, only 10 per cent of the wastes can go into the trunk sewer; the other 90 per cent must be treated by us and returned to the river in good condition. The Passaic River up to a few years ago had been an open sewer for the sanitary wastes and the mill wastes. Now the sewer is taking care of the sanitary wastes, and the mills are supposed to treat 90 per cent of their industrial wastes.

Passaic is on one side of the river and Carlton Hill, where the Standard Bleachery is located, is on the opposite side of the river, and I have noticed that the fish are now swimming up the Passaic River. Within the next few years probably all the industries down there will be taken care of and the river will be as nearly normal as before. In fact, motor boats are quite popular, where before they could not use the river. A white boat would turn black in a few weeks; and a white house a mile away would turn black from the fumes from the river. In my opinion it means that all large plants must install distillation systems of their own.

The Standard Bleachery Company was not compensated by the State or Government, in whole or in part, for the installation of its sewage disposal system.

Marcus K. Bryan.[5] There are two methods apparently used in this paper for the determination of value, one being used for condensing water and the other for industrial or process water. These are fundamentally different. The method used for condensing water is to capitalize the earnings accruing from the use of the condensing water, and the method used for the process water is to capitalize the average cost of water to several plants similarly situated. The method used for condensing water seems beyond criticism. There is a distinction between condensing water and process water which seems important to me, that being the fact that process water is indispensable and generally without a substitute, whereas condensing water is not essential in the operation of the plant. Thinking along that line, I wondered if the values established in the paper were not perhaps the minimum values. If the water supply is damaged, and the plant is reimbursed for the damages, that amount would, if capitalized, take account of the injury done to the earning power of the plant by the destruction or injury to the water supply. If a building or some other physical property or element of property were destroyed, it could be replaced, and perhaps its value would then be its replacement cost.

It is not likely that the destruction of a building would affect the earning power of the plant as destruction or elimination of the process water would, and the thought from that in my mind was that the difference between the values of water established in damages and the value established by the capitalized cost of obtaining it in the locality where the plant was located might be too large.

There appears to me another element of value in process water which has not been taken into account. Physical structures like buildings and machinery are replaced from time to time and depreciate in value, and generally are replaced with better buildings and machinery due to advances in the art. Supplies of process water, perhaps, are being depleted or the demand for them is increasing as industry increases, and may it not be that the value of process water appreciates through the years, and therefore might there be an element of value which admittedly is difficult to determine but is not in the values as determined?

### Author's Closure

I have not seen any report on the settlement of the claims and

[3] Pres., Curtis & Marble Mach. Co., Worcester, Mass. Mem. A.S.M.E.

[4] Standard Bleachery Co., Carlton Hill, N. J.

[5] Chas. T. Main, Inc., Boston, Mass. Mem. A.S.M.E.

counter-claims for damages to industrial plants on the Passaic River.

In order to keep the paper as simple as possible, I purposely omitted any discussion of the problem of getting rid of the water after it had been used for manufacturing purposes.

I am glad that Mr. Bryan has said something as this question has been under discussion among my associates for a number of years. Many thoughts relating to the subject have not been incorporated in the paper. The object was to see if we could get some reasonable method of determining the figures which we put into our valuations of industrial properties for the item of water for manufacturing purposes. If anybody can send in any discussion in writing which will be of assistance we shall be glad to have it.

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# Comparative Performance of Looms With Plain and Roller Bearings

By GEORGE H. PERKINS,[1] BOSTON, MASS.

THE tests reported in this paper were undertaken to obtain authentic comparative data on the effect of the application of roller bearings on loom performance, with special reference to the following factors:

1 Production gain
2 Maintenance cost
3 Power saving.

With this purpose, complete performance records were obtained from two groups of looms, each consisting of thirty-two 81-in. Hopedale "Nordray" automatics, in regular operation at the plant of the Naumkeag Steam Cotton Co., Salem, Mass.

These loom groups were identical in all respects, except for bearing equipment, and were under test and close observation for 26 full weeks of normal mill operation.

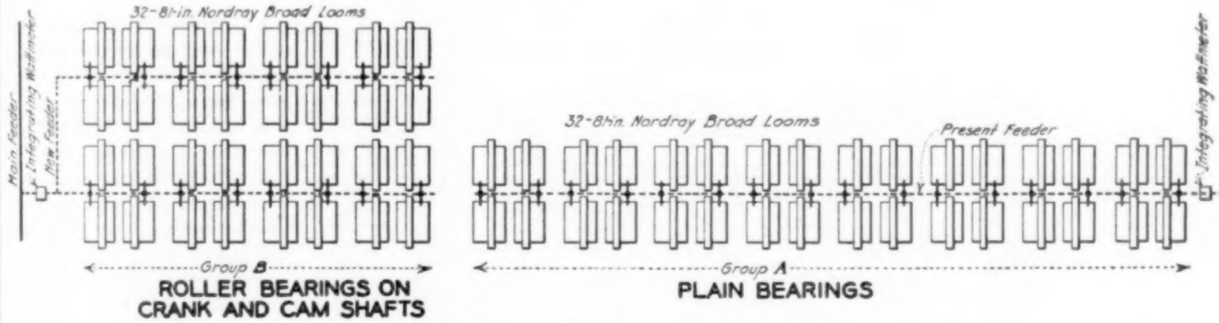


FIG. 1 LOOM ARRANGEMENT AT NAUMKEAG STEAM COTTON CO., SALEM, MASS.

Reliability of results was insured, not only by the long duration of the test and number of looms observed, but also by the elimination of such variable factors as age and condition of looms, type of drive, specification of cloth woven, atmospheric conditions, and character of attendance and supervision.

### General Data

| | |
|---|---|
| Plant | Naumkeag Steam Cotton Co., Salem, Mass. |
| Test started | March 14, 1927 |
| Test finished | Sept. 24, 1927 |
| Duration of test | 26 weeks. (Mill stopped for annual shutdown from July 2 to July 18 and also on holidays, April 19, May 30, and Sept. 5.) |
| Loom equipment | 81-in. Hopedale Manufacturing Co. Nordray automatic broad-sheeting looms |
| Age of looms | In use for 2 years, 6 months to Mar., 1927, including about 6 months of day and night operation |
| Motor equipment | $^{3}/_{4}$-hp. Design A, KT-121, General Electric Co. loom motors with waste-packed bearings, 1800 r.p.m., 220-volt, 3-phase, 60-cycle. Pinions: 15 teeth, 8 pitch, and $1^{1}/_{2}$-in. face |
| Pick-counter equipment | Veeder pick counters were used from Mar. 14 to July 2. All counters were changed during annual shutdown period. Root pick counters were used from July 18 to Sept. 24 |
| Normal loom speed | 115 picks per minute. Speed checked at frequent intervals |
| Cloth data | 81-in. Pequot brown sheeting, 68 ends, 72 picks, and 1.43 yd. per lb. |
| Watt-hour meters | Westinghouse Type OA watt-hour meter in feeder for each loom group. Meters were furnished and calibrated by Salem Electric Lighting Co., Salem, Mass. The meters were also recalibrated in test location on July 27, 1927 |
| Loom arrangement | The loom groups were arranged as shown on accompanying floor plan, Fig. 1. This plan also indicates location of watt-hour meters |
| Operating hours | 7:11 a.m. to 12 m. Monday to Friday, inclusive<br>12:56 p.m. to 5 p.m. Monday to Friday, inclusive<br>7:11 a.m. to 11:30 a.m. Saturday<br>Total time per week, 48 hr., 44 min.<br>Starting signal was given 4 minutes before "bell" time<br>All test looms were stopped promptly at 12 m. and 5 p.m. on Monday to Friday, inclusive, and at 11.30 a.m. on Saturdays |

| | Group A | Group B |
|---|---|---|
| Bearing equipment | 32 looms<br>All plain bearings throughout | 32 looms<br>Hyatt roller bearings<br>2 crankshaft bearings No. 311<br>Solid inner and outer races<br>Shaft diam.... 2.1665 in.<br>Bore.......... 4.7260 in.<br>Length....... $1^{15}/_{16}$ in.<br>2 camshaft bearings No. 18475<br>Split outer races<br>Shaft diam.... $2^{3}/_{16}$ in.<br>Bore.......... 3.6875 in.<br>Length....... 5 in.<br>All plain bearings on rocker shafts and friction shafts. |

### Test Methods and Observations

The general methods followed and principal observations taken during the test are outlined as follows:

1 *Production.* Pick-counter readings were taken on each loom daily after closing time.

All counter readings were recorded on a weekly record sheet and the total picks per loom per day and per week were computed and cross-checked at the end of each week's run.

2 *Maintenance.* All loom stoppages covering periods of 5

[1] Consulting Engineer, Boston, Mass. Mem. A.S.M.E.

Presented at the First National Meeting of the A.S.M.E. Textile Division, Boston, Mass., May 22, 1928.

TABLE 1 TYPICAL MAINTENANCE RECORD—LOOM NO. 3450, GROUP A

(Loom test at Naumkeag Steam Cotton Co.)

| Date (1927) | Stop | Start | Time lost, hr. | min. | Cause |
|---|---|---|---|---|---|
| Mar. 22 | 4:05 p.m. | 4:30 p.m. | | 25 | Replace pick cam point |
| Mar. 28 | 7:15 a.m. | 8:00 a.m. | | 45 | Repair shuttle |
| Mar. 29 | 7:15 a.m. | 7:30 a.m. | | 15 | Replace picker |
| Mar. 31 | 2:00 p.m. | 3:35 a.m. | 1 | 35 | New warp |
| Apr. 1 | 7:40 a.m. | 9:25 a.m. | 1 | 45 | Smash repair loom |
| Apr. 2 | 8:15 a.m. | 8:30 a.m. | | 15 | Replace rocker-shoe strap |
| Apr. 6 | 1:05 p.m. | 1:55 p.m. | | 50 | Smash |
| Apr. 11 | 10:00 a.m. | 10:10 a.m. | | 10 | New check strap |
| Apr. 11 | 11:00 a.m. | 11:22 a.m. | | 7 | New picker-stick bolt |
| Apr. 21 | 1:00 p.m. | 1:40 p.m. | | 40 | New shuttle |
| Apr. 21 | 3:00 p.m. | 3:30 p.m. | | 30 | New picker stick |
| May 2 | 11:25 a.m. | 11:45 a.m. | | 20 | Repair stop-motion casting |
| May 11 | 8:30 a.m. | 8:45 a.m. | | 15 | New lug clamp |
| May 19 | 1:30 a.m. | 1:40 a.m. | | 10 | New picker-stick bolt |
| June 4 | 9:00 a.m. | 9:20 a.m. | | 20 | New pick cam point |
| June 15 | 2:00 p.m. | 3:50 p.m. | 1 | 50 | New warp |
| June 21 | 1:30 p.m. | 2:00 p.m. | | 30 | New check strap, new lug strap |
| June 23 | 9:15 a.m. | 9:30 a.m. | | 15 | Pick-stick bolt |
| July 2 | 8:30 a.m. | 8:35 a.m. | | 5 | Pick-ball bolt |
| July 21 | 2:00 p.m. | 2:15 p.m. | | 15 | Pick cam point |
| July 21 | 3:40 p.m. | 3:50 p.m. | | 10 | New picker stick |
| Aug. 1 | 10:30 a.m. | 2:20 p.m. | 2 | 55 | New warp, new shuttle |
| Aug. 1 | 1:30 p.m. | 1:35 p.m. | | 5 | New bunter |
| Aug. 9 | 8:20 a.m. | 8:30 a.m. | | 10 | 2 picker-stick bolts |
| Aug. 17 | 3:40 p.m. | 3:50 p.m. | | 10 | Bushing for bunter |
| Aug. 19 | 1:30 p.m. | 1:45 p.m. | | 15 | 2 fuses |
| Aug. 24 | 4:25 p.m. | 9:25 a.m. | 2 | 50 | Protection rod, pick cam points, 1 motor fuse |
| Sept. 1 | 10:30 a.m. | 11:45 a.m. | 1 | 15 | New warp |
| Sept. 19 | 4:05 p.m. | 4:30 p.m. | | 25 | Pick cam point |
| Total | | | 19 | 32 | |

TABLE 3 COMPARISON OF PRODUCTION-POWER RATIOS FROM WEEKLY RECORDS

1000 picks per kw-hr.

| No. | Week ending (1927) | Group A, plain bearings | Group B, roller bearings | Percentage of gain, Group B over Group A |
|---|---|---|---|---|
| 1 | Mar. 19 | 10.76 (min.) | 11.79 | 9.66 |
| 2 | Mar. 26 | 10.84 | 11.58 (min.) | 6.83 |
| 3 | Apr. 2 | 10.80 | 11.90 | 10.02 (max.) |
| 4 | Apr. 9 | 10.99 | 11.85 | 7.82 |
| 5 | Apr. 16 | 11.00 | 12.03 | 9.36 |
| 6 | Apr. 23 | 11.48 | 12.02 | 4.70 |
| 7 | Apr. 30 | 11.25 | 11.75 | 4.44 |
| 8 | May 7 | 11.27 | 11.62 | 3.11 |
| 9 | May 14 | 11.08 | 11.91 | 7.49 |
| 10 | May 21 | 11.25 | 11.96 | 6.31 |
| 11 | May 28 | 11.66 | 12.04 | 3.26 |
| 12 | June 4 | 11.80 (max.) | 12.14 | 2.87 |
| 13 | June 11 | 11.75 | 12.00 | 2.13 (min.) |
| 14 | June 18 | 11.62 | 12.06 | 3.79 |
| 15 | June 25 | 11.44 | 11.84 | 3.49 |
| 16 | July 2 | 11.69 | 12.06 | 3.16 |
| 17 | July 23 | 11.52 | 11.94 | 3.65 |
| 18 | July 30 | 11.35 | 12.19 | 7.40 |
| 19 | Aug. 6 | 11.39 | 12.02 | 5.44 |
| 20 | Aug. 13 | 11.62 | 12.13 | 4.39 |
| 21 | Aug. 20 | 11.56 | 12.08 | 4.50 |
| 22 | Aug. 27 | 11.65 | 12.24 | 5.06 |
| 23 | Sept. 3 | 11.52 | 12.36 (max.) | 7.29 |
| 24 | Sept. 10 | 11.57 | 12.14 | 4.93 |
| 25 | Sept. 17 | 11.40 | 12.22 | 7.20 |
| 26 | Sept. 24 | 11.60 | 12.15 | 4.74 |
| Average for entire test | | 11.37 | 12.00 | 5.54 |

TABLE 2 SUMMARY OF WEEKLY RECORDS—LOOM TEST AT PLANT OF NAUMKEAG STEAM COTTON CO., SALEM, MASS.

| | | Group A 32 81-in. Nordray looms, plain bearings | | | Group B 32 81-in. Nordray looms, roller bearings | | | Gain for Group B over Group A | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Week ending (1927) | Total (1000) picks | Total power kw-hr. | 1000 picks per kw-hr. | Total (1000) picks | Total power kw-hr. | 1000 picks per kw-hr. | Production increase, per cent | Power saving, per cent |
| 1 | Mar. 19 | 9,902 | 920 | 10.76 | 10,024 | 850 | 11.79 | 1.23 | 7.60 |
| 2 | Mar. 26 | 10,083 | 930 | 10.84 | 10,194 | 880 | 11.58 | 1.09 | 5.38 |
| 3 | Apr. 2 | 9,818 | 910 | 10.80 | 10,119 | 850 | 11.90 | 3.07 | 6.60 |
| 4 | Apr. 9 | 9,788 | 890 | 10.99 | 10,073 | 850 | 11.85 | 2.92 | 4.49 |
| 5 | Apr. 16 | 9,882 | 900 | 11.00 | 10,105 | 840 | 12.03 | 2.28 | 6.66 |
| 6 | Apr. 23[1] | 8,154 | 710 | 11.48 | 8,295 | 690 | 12.02 | 1.70 | 2.81 |
| 7 | Apr. 30 | 9,906 | 880 | 11.25 | 10,137 | 860 | 11.75 | 2.33 | 2.27 |
| 8 | May 7 | 9,586 | 850 | 11.27 | 9,766 | 840 | 11.62 | 1.87 | 1.17 |
| 9 | May 14 | 9,867 | 890 | 11.08 | 10,011 | 850 | 11.91 | 1.46 | 5.62 |
| 10 | May 21 | 9,904 | 880 | 11.25 | 10,170 | 850 | 11.96 | 2.68 | 3.41 |
| 11 | May 28 | 10,030 | 860 | 11.66 | 10,239 | 850 | 12.04 | 2.08 | 1.16 |
| 12 | June 4[1] | 8,261 | 700 | 11.80 | 8,378 | 690 | 12.14 | 1.41 | 1.43 |
| 13 | June 11 | 9,874 | 840 | 11.75 | 9,974 | 830 | 12.00 | 1.01 | 1.19 |
| 14 | June 18 | 10,000 | 860 | 11.62 | 10,133 | 840 | 12.06 | 1.33 | 2.32 |
| 15 | June 25 | 9,837 | 860 | 11.44 | 10,066 | 850 | 11.84 | 2.27 | 1.16 |
| 16 | July 2 | 10,052 | 860 | 11.69 | 10,255 | 850 | 12.06 | 2.02 | 1.16 |
| 17 | July 23 | 10,020 | 870 | 11.52 | 9,910 | 830 | 11.94 | 1.11[2] | 4.51 |
| 18 | July 30 | 9,879 | 870 | 11.35 | 9,755 | 800 | 12.19 | 1.27[2] | 8.04 |
| 19 | Aug. 6 | 9,910 | 870 | 11.39 | 10,097 | 840 | 12.02 | 1.88 | 3.45 |
| 20 | Aug. 13 | 9,882 | 850 | 11.62 | 10,189 | 840 | 12.13 | 3.10 | 1.18 |
| 21 | Aug. 20 | 10,063 | 870 | 11.56 | 10,144 | 840 | 12.08 | 0.80 | 3.45 |
| 22 | Aug. 27 | 9,901 | 850 | 11.65 | 10,156 | 830 | 12.24 | 2.57 | 2.35 |
| 23 | Sept. 3 | 9,907 | 860 | 11.52 | 10,140 | 820 | 12.36 | 2.35 | 4.65 |
| 24 | Sept. 10 | 8,099 | 700 | 11.57 | 8,139 | 670 | 12.14 | 0.49 | 4.29 |
| 25 | Sept. 17 | 9,903 | 870 | 11.40 | 10,144 | 830 | 12.22 | 2.43 | 4.60 |
| 26 | Sept. 24 | 9,979 | 860 | 11.60 | 10,209 | 840 | 12.15 | 2.30 | 2.32 |
| | Total | 252,487 | 22,210 | | 256,822 | 21,410 | | | |
| | Average | 970 | 855 | 11.37 | 988 | 823 | 12.00 | 1.71 | 3.60 |

[1] Weeks including holiday.
[2] Loss.

minutes or over were carefully recorded by observer, including time of stop and start and the cause for the interruption of operation.

In case of all stoppages due to breakage, replacement, or repair the loom part involved, with name, pattern number, and cost, was recorded, together with the actual time lost.

All time required for changing warps was also recorded in the same manner.

A complete typical maintenance record for one loom No. 3450 of Group A is given in Table 1, and similar data were obtained for each of the test looms.

3 *Power.* Readings of the watt-hour meters on both groups were taken twice daily and records made on the weekly record sheet with the production.

Hourly readings were also taken on each Monday, beginning at 7:15 a.m. to determine the effect of the week-end shutdown on the starting power consumption.

4 *Observers.* Throughout the entire test an experienced observer, entirely familiar with loom operation and construction, was in constant attendance and recorded all of the test data.

5 *Weekly Records.* The complete results for each week for production and power were tabulated and computed on each original record sheet, which was duplicated, thus eliminating any errors resulting from transfer of data. Similar sheets were prepared for each of the 26 weeks of test.

6 *Attendance.* The test looms were operate d by the weavers and fixers regularly assigned to them, in the ratio of 12 looms per weaver and 50 looms per fixer.

## Test Data

The principal data of the test are shown in the accompanying tabulations as follows:

*Production and Power.* Table 2 gives the complete weekly and total results for production and power as follows:

*a* Weekly production for each group in (1000) picks (columns 3 and 6)

*b* Total production for each group in (1000) picks, with weekly average for test (columns 3 and 6)

*c* Percentage production gain for Group B over Group A for each week and average percentage for entire test (column 9)

*d* Weekly power consumption for each group in kw-hr. (columns 4 and 7)

*e* Total power consumption for each group for entire test in kw-hr., with weekly average for test (columns 4 and 7)

*f* Percentage power saving for Group B over Group A for

each week and average percentage for entire test (column 10)

*g* Ratio of production to power (1000 picks per kw-hr.) for each week and each group, with average ratio for entire test (columns 5 and 8).

In Table 3 the production power ratios are separately tabulated, and the percentage gain of these ratios for Group B over Group A is given by weeks and as an average for the entire test. All data in Table 3 are also shown graphically in Fig. 2.

*Maintenance Cost.* The complete summarized record of all replacements for every loom of both groups is given in Table 4. This table includes the name of part, pattern number, unit cost,

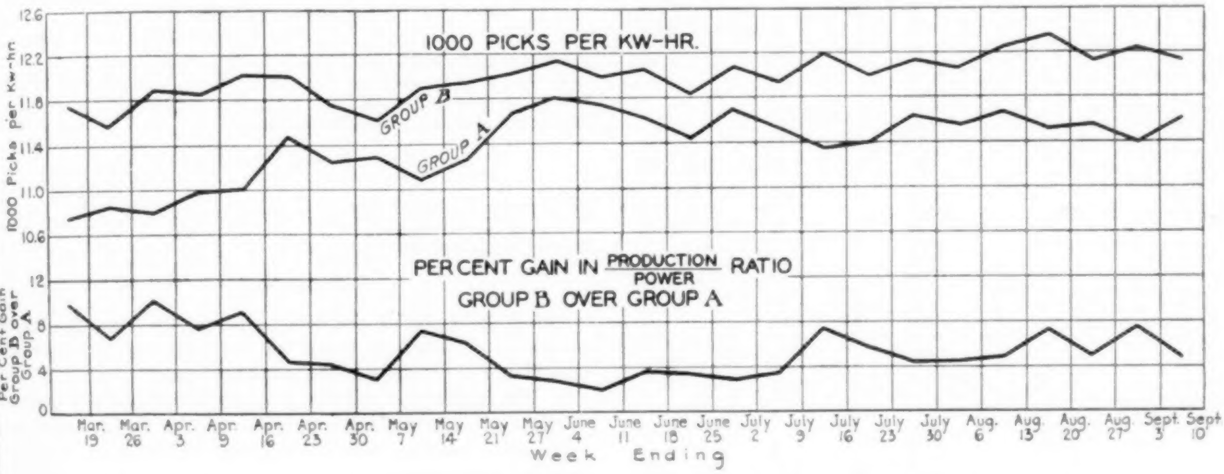


FIG. 2 COMPARISON OF PRODUCTION-POWER RATIOS OF LOOM TESTS AT NAUMKEAG STEAM COTTON CO.

actual number used, and total cost for all replacements made during the entire test.

### ANALYSIS OF RESULTS

Analyses of the test results in detail are presented as follows:

PRODUCTION

| | Group A, plain bearings | Group B, roller bearings |
|---|---|---|
| Total production (1000 picks) | 252,487 | 256,822 |
| Average (1000) picks per loom per week | 303.5 | 308.7 |
| Production: | | |
| Total, in yards | 97,410 | 99,082 |
| Yards per group per week | 3,746 | 3,811 |
| Yards per loom per week | 117 | 119 |
| Additional yards per loom per week | .... | 2 |
| No. of warps used during test | 156 | 167 |

The production gain for Group B shown above results from easier and smoother loom operation, with consequent less stoppage for repairs, replacements, and normal loom operations by the weavers.

The following tabulation presents a segregation of the total test time in loom-hours and in percentages of total.

TIME ANALYSIS

| | Loom-Hours | | | |
|---|---|---|---|---|
| | Group A | Per cent | Group B | Per cent |
| Total productive time | 36,592 | 92.02 | 37,220 | 93.59 |
| Total stoppage for changing warps | 303 | 0.76 | 302 | 0.75 |
| Total stoppage for replacements and repairs | 260 | 0.66 | 113 | 0.28 |
| Total stoppage for normal loom operation | 2,610 | 6.56 | 2,130 | 5.38 |
| Total test time | 39,765 | 100.00 | 39,765 | 100.00 |
| Total stoppage time | 3,173 | 7.98 | 2,545 | 6.41 |
| Average loom efficiency, per cent | | 92.02 | | 93.59 |

*Maintenance.* Study of the maintenance records (Table 4) shows a large proportion of the replacements for both groups to be parts of the pick motion and related members such as check straps, lug straps, pick cam points, pickers, picker sticks and bolts, rocker shoes and bolts, and shuttles. These parts are subjected to repeated shocks and always comprise the major part of loom upkeep.

These parts for both groups are segregated in the following comparative table:

NUMBER OF PARTS REPLACED

| | Group A, plain bearings | | Group B, roller bearings | |
|---|---|---|---|---|
| | No. | Cost | No. | Cost |
| Check straps | 31 | $1.86 | 13 | $0.78 |
| Lug straps | 8 | 0.84 | 4 | 0.42 |
| Pick cam points | 18 | 9.90 | 8 | 4.40 |
| Pickers | 51 | 4.59 | 14 | 1.26 |
| Picker sticks | 39 | 2.14 | 23 | 1.26 |
| Picker-stick bolts | 34 | 1.02 | 14 | 0.42 |
| Rocker shoes | 5 | 2.25 | 2 | 0.90 |
| Rocker-shoe bolts | 14 | 0.42 | .. | .... |
| Shuttles | 21 | 30.24 | 8 | 11.52 |
| Total cost | | $53.26 | | $20.96 |

The marked reduction in the number of these parts for Group B must be attributed to the shock-absorbing characteristics of the roller bearings used.

*Power.* The following table gives a summary of the power data obtained for the entire test.

| | Group A, plain bearings | Group B, roller bearings |
|---|---|---|
| Total power for test, kw-hr | 22,210 | 21,410 |
| Average kw-hr. per week | 855 | 823 |
| Max. kw-hr. per week | 930 | 880 |
| Min. kw-hr. per week including holiday | 700 | 670 |
| Total loom hours | 39,765 | 39,765 |
| Kw. per loom per hr. | 0.56 | 0.54 |
| Hp. per loom per hr. | 0.751 | 0.723 |
| Rated hp. of motors | 0.75 | 0.75 |
| No. of motor fuses replaced | 21 | 5 |

Study of the weekly power consumption in Table 2 shows a marked consistency throughout, and that practically all variations

TABLE 4 MAINTENANCE RECORD FOR 26-WEEK PERIOD ENDING SEPT., 1927—LOOM TESTS AT NAUMKEAG STEAM COTTON CO.

| Replacements (Name of part and pattern No.) | Cost each | Group A, plain bearings, 32 looms No. | Group A Total cost | Group B, roller bearings, 32 looms No. | Group B Total cost |
|---|---|---|---|---|---|
| Binders | $0.23 | 2 | $0.46 | 1 | $0.23 |
| Binder bushing (L-2957) | 0.18 | .. | ..... | 1 | 0.18 |
| Binder holder (M-7219) | 0.90 | .. | ..... | 1 | 0.09 |
| Binder holder (H-1610) | 0.90 | 1 | 0.90 | .. | .... |
| Brake casting (H-2007) | 0.50 | 1 | 0.50 | .. | .... |
| Brake casting (H-2789) | 0.25 | 1 | 0.25 | .. | .... |
| Battery spring | 0.03 | 1 | 0.03 | .. | .... |
| Battery casting (B-20) | 0.30 | 6 | 1.80 | 2 | 0.60 |
| Battery casting (B-5016) | 0.15 | .. | ..... | 1 | 0.15 |
| Battery casting (C-396) | 2.60 | 1 | 2.60 | .. | .... |
| Bobbin guard (L-19672) | 0.35 | .. | ..... | 1 | 0.35 |
| Box plate set screw | 0.03 | 2 | 0.06 | .. | .... |
| Bunters | 0.10 | 8 | 0.80 | 3 | 0.30 |
| Check strap bolts | 0.02 | 2 | 0.04 | .. | .... |
| Check strap | 0.06 | 31 | 1.86 | 13 | 0.78 |
| Check strap casting (H-1677) | 0.30 | 1 | 0.30 | .. | .... |
| Check strap casting (L-19597) | 0.29 | 1 | 0.29 | 1 | 0.29 |
| Crank-arm | 0.28 | 1 | 0.28 | .. | .... |
| Crank-arm bolt | 0.02 | 7 | 0.14 | .. | .... |
| Crank arm clamp | 0.16 | 1 | 0.16 | .. | .... |
| Friction gear, large (H-1910) | 14.50 | 2 | 29.00 | .. | .... |
| Friction gear, small | 2.90 | 1 | 2.90 | .. | .... |
| Fiber washer on friction | 0.16 | 2 | 0.32 | 1 | 0.16 |
| Filling fork (H-1781) | 0.50 | 3 | 1.50 | .. | .... |
| Filling-fork holder | 0.50 | 1 | 0.50 | .. | .... |
| Gear bolt | 0.05 | 1 | 0.05 | .. | .... |
| Harness cam (H-1789) | $1.40 | .. | ..... | 1 | $ 1.40 |
| Harness strap | 0.15 | 1 | 0.15 | 1 | 0.15 |
| Heel strap spring (L-864) | 0.08 | 1 | 0.08 | .. | .... |
| Let-off bolt | 0.02 | 1 | 0.02 | .. | .... |
| Let-off casting (H-1720) | 0.24 | .. | ..... | 1 | 0.24 |
| Let-off friction clamp (H-1800) | 0.20 | 1 | 0.20 | .. | .... |
| Let-off gear (L. M.-3789) | 0.41 | 1 | 0.41 | .. | .... |
| Let-off gear spring | 0.20 | 1 | 0.20 | .. | .... |
| Lug bolt | 0.02 | 1 | 0.02 | 3 | 0.06 |
| Lug clamp | 0.05 | 1 | 0.05 | .. | .... |
| Lug strap | 0.10½ | 8 | 0.84 | 4 | 0.42 |
| Motor fuses | 0.15 | 21 | 3.15 | 5 | 0.75 |
| Mouth piece (H-1611) | 0.40 | 2 | 0.80 | .. | .... |
| Mouth piece bolts | 0.03 | 2 | 0.06 | .. | .... |
| Pick ball stand (L-17880) | 0.99 | .. | ..... | 1 | 0.99 |
| Pick cam points (H-1572) | 0.55 | 18 | 9.90 | 8 | 4.40 |
| Pickers | 0.09 | 51 | 4.59 | 14 | 1.26 |
| Picker stick bolts | 0.03 | 34 | 1.02 | 14 | 0.42 |
| Picker sticks | 0.05½ | 39 | 2.14½ | 23 | 1.26½ |
| Protection rod, right | 1.30 | 1 | 1.30 | 1 | 1.30 |
| Pick ball bolts | 0.04 | 3 | 0.12 | 3 | 0.12 |
| Protection rod casting (L-22315) | 0.24 | .. | ..... | 2 | 0.48 |
| Protection rod casting (H-11612) | 0.40 | .. | ..... | 1 | 0.40 |
| Pick arm casting (H-1569) | 1.26 | 5 | 6.30 | 3 | 3.78 |
| Pick ball washer (L-12838) | 0.04 | 3 | 0.12 | 2 | 0.08 |
| Protection rod casting (H-1514) | 0.24 | .. | ..... | 1 | 0.24 |
| Pick cam bolts | 0.04 | 2 | 0.08 | 1 | .... |
| Picker straps | 0.12 | 1 | 0.12 | .. | .... |
| Pick-arm bolts | 0.02 | 1 | 0.02 | .. | .... |
| Pick ball (L-12728) | 0.24 | 4 | 0.96 | 2 | 0.48 |
| Pick ball casting (L-1996) | 0.09 | 1 | 0.09 | .. | .... |
| Rocker shoes | 0.45 | 5 | 2.25 | 2 | 0.90 |
| Rocker shoe bolts | 0.03 | 14 | 0.42 | .. | .... |
| Rocker shoe straps | 0.03 | 5 | 0.15 | 4 | 0.12 |
| Rocker shoe tongue (H-2009) | 0.20 | 4 | 0.80 | 3 | 0.60 |
| Roller bearing casing (Hyatt) | 3.00 | .. | ..... | 1 | 3.00 |
| Rocker shoe, top (M-1862) | $1.40 | .. | ..... | 2 | $ 2.80 |
| R. H. parallel (L-28307) | 0.94 | 1 | 0.94 | .. | .... |
| Shafting keys | 0.04 | 3 | 0.12 | .. | .... |
| Shuttles | 1.44 | 21 | 30.24 | 8 | 11.52 |
| Shippers (H-1997) | 0.60 | 2 | 1.20 | 8 | 4.80 |
| Shipper handle bracket (H-1918) | 0.20 | 1 | 0.20 | 3 | 0.60 |
| Shipper handle casting (H-1996) | 1.80 | .. | ..... | 3 | 5.40 |
| Shipper lock (H-1998) | 1.45 | 1 | 1.45 | 3 | 4.35 |
| Stop motion link (W-1288) | 0.40 | 2 | 0.80 | 2 | 0.80 |
| Stop motion casting (W-1290) | 0.20 | 1 | 0.20 | .. | .... |
| Shuttle box plate (H-1516) | 2.05 | 3 | 6.15 | .. | .... |
| Stop motion wire | 0.08 | .. | ..... | 3 | 0.24 |
| Temple | 3.25 | 1 | 3.25 | .. | .... |
| Temple rolls | 0.25 | .. | ..... | 4 | 1.00 |
| Temple cutters | 0.40 | 2 | 0.80 | .. | .... |
| Temple cutter spring | 0.03 | 1 | 0.03 | .. | .... |
| Temple slide | 0.12½ | .. | ..... | 1 | 0.12½ |
| Take-up gear | 1.05 | 1 | 1.05 | .. | .... |
| Take-up casting (H-1782) | 0.40 | 3 | 1.20 | .. | .... |
| Take-up casting (H-1932) | 0.20 | 1 | 0.20 | .. | .... |
| Take-up casting (H-1764) | 1.00 | 1 | 1.00 | .. | .... |
| Take-up casting (H-1754) | 0.55 | 1 | 0.55 | .. | .... |
| Temple (T-319) | 1.30 | .. | ..... | 1 | 1.30 |
| Tongue (L-28016) | 0.25 | 1 | 0.25 | 1 | 0.25 |
| Bobbin chute (L-19672) | 0.35 | .. | ..... | 1 | 0.35 |
| Dagger finger (H-1612) | 0.40 | .. | ..... | 1 | 0.40 |
| Front box plate (L-24889) | 0.27 | 1 | 0.27 | .. | .... |
| Pick ball spring (H-1735) | 0.15 | .. | ..... | 1 | 0.15 |
| Pick cam hub (M-7122) | 4.75 | .. | ..... | 1 | 4.75 |
| Grand total, cost for 26 weeks | | | $131.00 | | $65.62 |
| Average cost per loom per week | | | $ 0.1574 | | $ 0.0789 |

in power are directly reflected in changes in the production obtained for same period.

The ratios of production to power in thousands of picks per kilowatt-hour as shown in Table 3 are particularly consistent throughout the entire test.

## Summary of Results

The principal results of the test are summarized as follows:

### Production Gain

| | Group A | Group B |
|---|---|---|
| Total production for test, yards | 97,410 | 99,082 |
| Production gain for test, yards | ... | 1,672 |
| Production gain over Group A, per cent | ... | 1.71 |
| Production gain per loom per week, yards | ... | 2 |
| Production gain per loom per year (50 weeks), yards | ... | 100 |

### Maintenance Cost

| | Group A | Group B |
|---|---|---|
| Total cost of replacements for test | $131.00 | $65.62 |
| Cost per loom per week | 0.1574 | 0.0789 |
| Saving per loom per week | ....... | 0.0785 |
| Saving per loom per year (50 weeks) | ....... | 3.93 |

### Power Saving

| | Group A | Group B |
|---|---|---|
| Total power for test, kw-hr | 22,210 | 21,410 |
| Power saving, kw-hr | ... | 800 |
| Power saving, per cent | ... | 3.6 |

## Conclusions

Before summarizing the conclusions drawn from these tests, particular attention is called to the following factors which have important bearing on the results obtained:

1 The application of roller bearings to the looms of Group B was limited to four bearings only per loom out of a possible ten.

No roller bearings were used on the friction shafts or rocker shafts of either group.

This limited application of roller bearings unquestionably restricted to some extent the advantages to be gained from their use.

2 In comparing the loom efficiency of both groups, special note should be made of the high existing efficiency of the looms of Group A. This fact makes any production gain shown the more creditable.

3 The existing loom conditions of Group A were excellent, and particular attention was given to general upkeep and systematic lubrication. These favorable conditions have an important bearing on the possible power savings.

The following factors all contribute largely to the authenticity of the results under the conditions as outlined:

1 Duration of test
2 Number of looms operated
3 Elimination of variable factors and uniformity of conditions
4 Close observation of all looms for all stoppages for any cause.

In view of the above factors and the marked consistency of all observations throughout the test, the following conclusions may be drawn:

1 The production gain of 1.71 per cent obtained for Group B results directly from the use of the roller bearings, through effecting easier- and smoother-running looms and thus reducing the stoppage time for repairs, replacements, and the normal operations incident to weaving. The commercial value of the increased production varies so widely in different plants that no attempt will be made by the author to present definite cost data in this paper.

2 The material reduction of maintenance cost must be directly attributable to the application of roller bearings, through the partial elimination of the shocks incident to loom operation, particularly in connection with the pick motion.

3 The net power saving shown (3.6 per cent), while not large, is creditable in view of the limited bearing application and generally excellent condition of the looms with plain bearings. Power saving must always be considered secondary to the gain in production and the reduction of maintenance costs. The value of this power saving will vary in different localities with the cost of power, and this gain will therefore not be evaluated in this paper.

It should be noted that these tests were made in a modern textile mill of the highest type and one widely known for its efficiency. Larger production gains and increased savings in power and maintenance costs could undoubtedly be shown in the textile mill of average efficiency.

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# Progress in the Woodworking Industries

## Contributed by the Wood Industries Division

Executive Committee: Wm. Braid White, *Chairman,* Paul H. Bilhuber, *Secretary,* James S. Mathewson, Sern Madsen, and Thos. D. Perry

DURING the past year the wood industries of the United States have shown, by and large, a growing interest in the fundamental question of the quantity and quality of the remaining supplies of domestic timber. In part this interest has been due to the work of the National Committee on Wood Utilization, which was set up three years ago by Secretary Hoover of the Department of Commerce, and which is composed of representatives of the lumber, woodworking, forestry, and engineering interests. The A.S.M.E., in the person of the present chairman of the Wood Industries Division, is represented on this committee, which is working to educate the wood industries in eliminating waste, in the need for an understanding of scientific methods of timber conservation, and in preparing the way for the ultimate adoption of standards in machinery and in machine methods. The work of this committee is by no means the only work of the kind being done, but it must be mentioned as a contributing factor to the year's progress.

Not enough has become known among the industries, metal and non-metal alike, concerning the very fine work which has been going on for a number of years at Madison, Wisconsin, where the Forest Products Laboratory of the Forestry Service of the United States carries on its increasingly valuable researches into every aspect of the growth and use of wood. The practice of throwing open to technical men from the woodworking industries free courses at the Laboratory in the gluing of wood, in the science and art of plywood building, in crating and boxing, and especially in the seasoning and drying of lumber, has been continued, and it may confidently be affirmed that all who have had personal contact with these admirable courses of instruction feel more than repaid for the time spent in them. If the woodworking industries were more alive to the work which the Forest Products Laboratory is doing, they would be insistent in pressing Congress to be more generous in appropriating the needed funds.

### Timber Conservation

Timber conservation is no longer a matter merely of academic interest. At the annual convention of the National Lumber Manufacturers' Association, held this summer in Chicago, the tone of the discussions was extremely serious, indicating clearly that the lumber men, who have been the chief scorners of all talk about diminishing supplies, are themselves already thoroughly alarmed at the situation. This fact lends point to the position taken by the Wood Industries Division of the A.S.M.E., which two seasons ago undertook to investigate the situation as to possible supplies of commercially and industrially usable timbers from tropical countries, such as the Philippines, British India, and Central and South America. In the Progress Report of one year ago it was possible to say something briefly about this research, and now, a year later, it can be stated that some quite definite steps have been taken. A comprehensive bibliography of books, papers, and articles in several languages, upon every aspect of the tropical-woods question, has been prepared by Major George P. Ahern and Miss Helen Newton of the Tropical Plant Research Foundation of Washington, D. C. In addition to this extremely valuable pioneer work, which is paving the way for the scientific investigation of a subject as important as it is little understood, the Wood Industries Division has given special attention to presenting aspects of the question at various meetings of the Society. Thus, at the first national wood industries meeting of the A.S.M.E., held last November in Chicago, after the 1926 Progress Report had been written, the whole question of timber supply was taken up by Major Ahern, whose paper produced valuable discussions and debates, in which experts from the Forest Products Laboratory, tropical foresters, and representatives of large wood-using industries took part. At the second national wood industries meeting of the Society, held in Grand Rapids during the month of October last, the same subject was taken up again, and has come to general attention.

### Research

Last year's report made mention of a project to secure a research into the properties of machine saws and cutting blades, investigating the laws governing the behavior of these tools in use, and leading to the formulation of recommendations to manufacturers and users whereby closer agreement may be arrived at in regard to saw cuts, sharpening, standardization of cutting edges, etc. Considerable difficulty was experienced in obtaining a working committee, but the task has now been accomplished and the first general meeting will have been held before this report has been published.

The research in spark-arrester design and use is proceeding through the help and cooperation of the Pacific Coast Local Sections of the A.S.M.E.

### Progress in Developing Woodworking Machinery Along Engineering Lines

Last year some mention was made of the subject of woodworking education, with special reference to the attitude assumed by directors of technical schools and colleges. It is not possible at this time, unhappily, to say anything more encouraging than was said a year ago. Woodworking remains, in the minds of engineering educators, the cut-and-fit art it was a generation or two since; nor is there much probability of fruitful change save through the direct intervention of the woodworking industries, and their insistence upon a proper appreciation of the fact that woodworking has now perforce been driven into the engineering ranks.

Meanwhile it is possible to say something more or less definite about the progress which has been made during the year in developing woodworking machinery along engineering lines.

In the first place, there can be no doubt as to the trend of design of woodworking machinery. It is toward inbuilt electric motors, rendering each machine self-contained. In the same way one may note a trend toward the adoption of multiple-operation machines, while frequency changers are being more and more used to give machines the advantage of both high- and low-speed operation. This practice is becoming more and more common in connection with shaping, grinding, jointing, and (some types of) planing machines.

Another new departure is to be found in the gradual invasion of the field by tools driven by compressed air, and some newly designed shapers and routers so driven are being successfully

exploited. The primary cost of compressed-air operation is greater than where electric current is used, but the maintenance cost is sufficiently lower to offset this in most cases.

The use of high-speed steel for cutter heads and milled knives is also developing, and in shapers, matching, and molding machines cutting tools made of this material are rapidly replacing the older carbon-steel types.

It is worth noting that the speed and accuracy of woodworking machinery are often underrated by engineers who are not closely in touch with modern mill developments. The fact that wood is a material relatively easily worked sometimes is allowed to obscure the equally important fact that woodworking machinery is keeping all the time a little ahead of its material and is constantly being adapted to closer, more accurate, and more rapid operation. Even if the factor of rapidity be left out of the picture, it is certain that all these developments make in their way for conservation of a timber supply already dangerously depleted.

Turning again for a moment to this question of the supply of the raw material of woodworking—the timber itself—it is interesting to note that in addition to the movements mentioned at the beginning of this Report, others have been initiated by the lumber interests. Among these may be mentioned:

1 Completion and adoption of the American Lumber Standards for softwood, thereby unifying sizes, grades, and shipping practice in respect of by far the greater part of all such lumber annually produced in this country;

2 Steady development of hardwood grading standards;

3 National waste-prevention contests, bringing out new machinery, methods, and suggestions for preventing waste, using materials now being wasted, and improving the quality of the product from the log; and

4 Adoption of a research program covering the properties and uses of wood.

### Wood Finishes

In the domain of wood finishing, it is worth noting that the use of nitrocellulose solutions (known as "lacquers") in the place of varnishes has been steadily increasing during the past year. More than half of all the furniture exhibited at the winter and summer furniture shows this year was lacquer-finished. The difficult technical problems of applying these new finishes to woods are gradually being worked out, and woodworkers are coming to regard lacquer as not merely interesting and novel, but as definitely valuable and advantageous when rightly prepared, applied, and managed. It is distinctly pleasing at this point to discover that one result of the growing interest in these lacquer finishes is to be found in definitely improved work in the sanding of wooden parts as they come from the mill, in preparation for the application of the lacquer. Clean and smooth sanding is necessary when lacquers are used, and of course there are numerous other subsidiary advantages to the finished product, flowing from this improved practice.

The research into the possible use of tropical hardwoods, reported here as part of the work of the Wood Industries Division of the A.S.M.E., is being backed up practically by certain woodworking industries, which report trials, and in some cases adoption, of tropical hardwoods in place of domestic varieties, but the subject is still in too indefinite a shape for more positive comment.

Plywood continues to find favor where strength and resisting power are factors, and the art of fashioning it continues to become more exact, thus tending to the utilization of woods which otherwise in many cases have been wasted.

The evolution of the wood industries into engineering arts proceeds steadily, and the place of the woodworking technicians among the members of the A.S.M.E. becomes yearly more thoroughly justified.

Wm. Braid White, *Chairman.*

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# Increasing the Production of Woodworking Machines by Use of Direct-Connected Alternating-Current Motors

By W. A. FURST,[1] DETROIT, MICH.

THE electrical industry has continuously kept pace with the progress of woodworking machine-tool development. This mutual and coordinated progress has attained results almost undreamed of a few years ago. The aim of both the builder of machine tools and the builder of electrical equipment has been to coordinate their efforts with the greatest economy and the highest utility, and, with but few exceptions, the individual electric drive of machine tools has met the demands of the most progressive and exacting ultimate users.

For an example, let us take an individual machine, such as a molder or planer and matcher. If this machine were belt-driven there would probably be a countershaft connected with a main lineshafting, or a single motor coupled to the countershaft, and also the necessary belt running from the countershaft to the machine and the necessary belts on the machine which would take care of the cutter heads and the feed of the machine. Old-timers are familiar with the maintenance required for the belts, pulleys, bearings, etc. of an installation of this character. We all know that with the belt drive there is a limit to the operating speed as determined by the permissible linear speed of the belt in feet per minute. We know also that to obtain the best results on a finished surface it is desirable to have the greatest number of knife marks per inch length of material. To obtain the most desirable number of cuts with a belt-driven machine it is necessary to assume a maximum belt speed of possibly 5000 to 6000 ft. per min., and also to use a cutter head having a large number of knives. Any operator who has had the task of setting up and grinding knives on a cutter head appreciates what is required to set and grind a knife head of this character.

An advantage which may be gained by using direct-connected motor drive—that is, a built-in individual motor on each cutter head, and in addition a motor on the feed—is the possibility of using a cutter head with fewer knives and of running the motor at a higher speed than attainable by the use of a belt drive. Further, with the use of individual motor drive it is possible to operate any one head individually, allowing the other head to remain idle. Another decided advantage is that if the work becomes jammed in the machine the cutter head will automatically stop, because of the overload protection on the motor, which latter may be arranged so that jamming or other trouble on any one cutter head will immediately stop all cutter heads and the feed mechanism at the same time. This is impossible in the case of a belt-driven machine unless the belt slips off or breaks. As to the class of work accomplished, if the belt is loose enough to slip it means that the tool or cutter head will slow up when it is passing over a hard spot in the material, whereas the electric motor will have a tendency to maintain practically a constant speed at all times and give the same finish over the whole length of the material.

Up to the present time the standard alternating-current motor with a full-load speed of approximately 3500 r.p.m., operating on a 60-cycle circuit has been applied to the cutter heads on the above-mentioned machine. To increase the production of the plant it is quite possible and feasible to take the standard motors which were normally designed for 60-cycle service and increase the frequency and voltage of the main circuit in direct proportion so that higher speeds may be obtained on the cutter heads. Under this condition, assuming that the feed remains the same, we should obtain a greater number of knife marks per inch length of material, and thereby obtain a smoother surface. However, by increasing the speed of the cutter head and the feed at the same time we are able to increase the production of the machine in a direct ratio with the speed of the cutter head and in accord with the class of work desired. By this is meant that if a high grade of finish is desired the cutter heads should be increased in speed but the feed should remain the same. However, if the same results are desired as are being obtained under present conditions the feed should be increased in the same proportions as the speed of the cutter head.

The following information will be of interest to those desiring to increase the production of their machines, using motors direct-connected to the cutter heads.

The feed motor may be designed for four-speed operation with approximately a 3 to 1 ratio, that is, having a high speed of approximately 1800 r.p.m. in four steps, giving respectively 1800, 1200, 900, and 600 r.p.m.

When we speak of the ordinary standard alternating-current motor we at once think of a motor operating on a 60-, 50-, or 25-cycle circuit. By "cycle" in alternating current we mean that the current builds up from zero to its maximum, and returns to zero again and then does so in the opposite direction for the succeeding half cycle. There are two alternations for each cycle. By the number of cycles—that is, 60, 50 or 25—we mean the number of complete cycles per second. In other words, in a 60-cycle circuit there are 7200 alternations per minute. To obtain the various speeds, the motors are built with different numbers of poles. In practice these run in multiples of 2, from 2 to the upper limit of 18. For the smaller-sized motors it is not desirable to have a large number of poles as it makes the cost prohibitive because of the considerably greater amount of labor and material required in winding.

As the speed of an alternating-current motor is determined by the number of poles of the motor and the frequency of the supply circuit, this can be expressed by the following formula:

$$\text{R.p.m.} = \frac{f \times 60 \times 2}{N} = \frac{f \times 120}{N}$$

where $f$ is the frequency of the line and $N$ the number of poles.

The high-speed motors are of the same simple construction as standard squirrel-cage motors. They consist (Fig. 1) of two main parts, namely, the stator or stationary part and the rotor or rotating part. The speed of these motors ranges from 3600 to 18,000 r.p.m.

Up to the present time 18,000 r.p.m. has apparently been the highest speed required in commercial practice; however, it is quite feasible to obtain higher speeds, and motor manufacturers

[1] Manager Engineering Division, Westinghouse Electric & Manufacturing Company.

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are prepared to quote on such motors as special applications. By referring to Fig. 2, the speeds for 2-, 4-, 6-, and 8-pole motors at various frequencies can be readily noted. For example, a 2-pole motor operating on a 120-cycle line will run at 7200 r.p.m., or operating at 200 cycles the same motor will have a speed of 12,000 r.p.m.

The speeds as given on this chart are the synchronous or no-

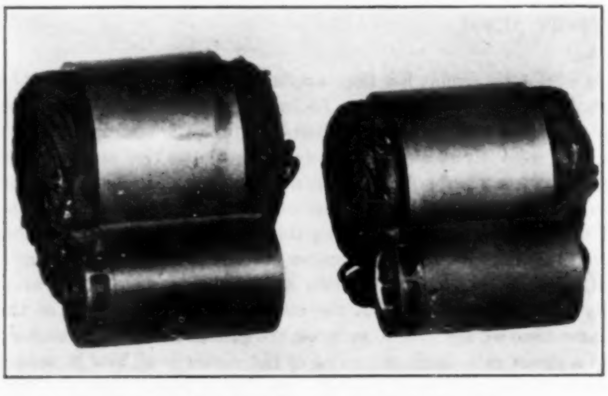

FIG. 1 STANDARD SQUIRREL-CAGE MOTORS

load speeds. The drop in speed of an induction motor from no load to full load, or the slip, is proportional to the amount of resistance in the rotor or rotating circuit. As the starting torque of the motor is directly dependent upon the amount of slip of the rotor, it can be seen that for various applications the slip of the motor should be different, and therefore the full-load speed will necessarily be lower with the higher slip. In most cases it is very easy to figure the full-load speed from the curve, knowing the slip. In the standard motor the slip is usually from 2 to 5 per cent, but where the starting conditions are severe, small motors may have a slip as high as 10 per cent. This probably would be an exceptional case, and the motor would

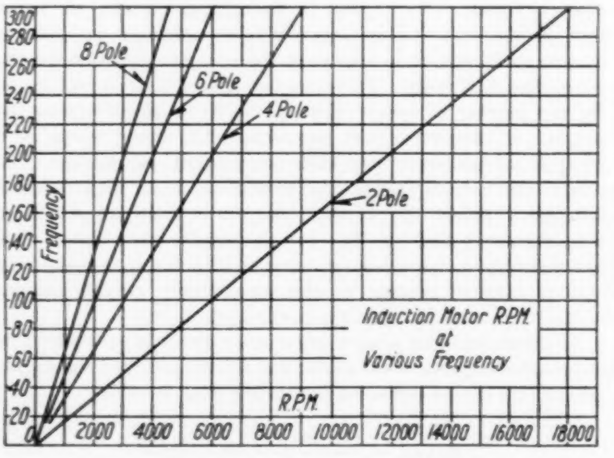


FIG. 2 INDUCTION-MOTOR SPEEDS AT VARIOUS FREQUENCIES

only have this high percentage of slip when the starting torque was very high. Assume, for example, that a motor has a slip of 5 per cent and a synchronous speed of 7200 r.p.m. The full-load speed would then be 7200 r.p.m. minus 5 per cent of 7200 r.p.m. or 6840 r.p.m.

In this class of high-speed motors the ratings are all based on a continuous duty, with a temperature rise of 40 deg. cent., and the motors are designed to operate at various frequencies, depending upon what speed is desired up to certain limitations for the particular size employed. For the larger sizes, such as those used on molders or planers and matchers, 6000 r.p.m. at 100 cycles apparently is the maximum speed at which it would be desirable to run the cutter head. For the smaller-sized motors, where a smaller cutter head is used, such as on spindle shapers and carving machines, higher motor speeds may be obtained in proportion. By referring to Fig. 3, at the right-hand columns B and C, it will be noted that the voltage varies at the different frequencies given in column A. In the case of a 110-volt motor operating at 120 cycles, it would require 165 volts at 180 cycles, and when operating at 60 cycles, 55 volts. If the motor is designed for 220 volts and 60 cycles, the values in column C should be multipled by four. However, if the motor is designed for 440 volts at 60 cycles, column C should be multiplied by eight. It can readily be appreciated that at 100 cycles this would give approximately 756 volts at the motor. Under this condition of operation it would be desirable to change the motors over from 440-volt connection to 220 volts at 60 cycles and then have them operate at approximately 396 volts at 100 cycles. However, if it were desired to operate the 440-volt motors at 60 cycles to a speed of approximately 4800 r.p.m. or 80 cycles, the voltage then would rise only to approximately 584 volts.

For any conditions which arise on this subject wherein the motors in use are to be operated at higher frequencies, the subject should be referred to the manufacturers of the electrical

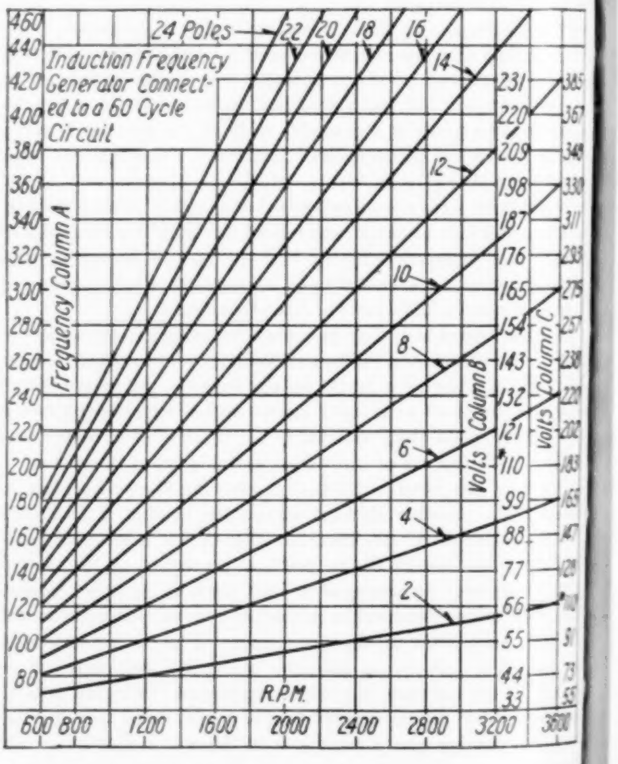


FIG. 3 FREQUENCY-SPEED-VOLTAGE RELATIONS OF AN INDUCTION FREQUENCY GENERATOR CONNECTED TO A 60-CYCLE CIRCUIT

equipment for their comments and recommendations. As stated above, in some cases the present motors may be operated at the higher frequencies and voltages without any change whatsoever in the connections of the motors.

By referring to columns B and C of the chart, at 300 cycles the motor designed to operate at 110 volts and 200 cycles would operate at 168 volts and 300 cycles, while the motor designed for 110

volts and 120 cycles would have to operate at 275 volts and 300 cycles, and if it had been designed for 220 volts and 120 cycles, it would operate at twice 275 volts, or 550 volts. Because of the necessary insulation required for this voltage and the restricted space available on these comparatively small motors, it is desirable to keep the voltage as low as possible. This requirement is to a certain extent governed by local conditions in the operating plant, and it is highly desirable in all cases to get the recommendations of the motor manufacturer for the various voltages to be used.

Probably the majority of the motors employed in the woodworking industry have 2, 4, 6, or 8 poles. The synchronous speed of an alternating-current motor is obtained by dividing the number of alternations per minute by the number of poles. For example, consider a 2-pole motor operating on a 60-cycle circuit; 60 cycles is equivalent to 7200 alternations per minute, which, divided by 2, gives a motor speed of 3600 r.p.m. Since a motor may not have less than two poles, 3600 r.p.m. is therefore the maximum speed which can be obtained on a 60-cycle source of supply. Therefore in order to obtain higher speeds it is necessary to increase the frequency, or the number of cycles per second.

There are several methods of obtaining high frequency for operating high-speed motors. Probably the simplest one is by utilizing the induction frequency changer. This consists essentially of a standard wound-rotor type of alternating-current motor with certain modifications in the design so that it will give the proper voltage at any predetermined frequency. It can only be used where alternating current is available, irrespective of the frequency of the incoming line. The fundamental theory of this generator is such that it has virtually the same characteristics as an ordinary transformer.

If we take a standard alternating-current wound-rotor type of motor, pass a 60-cycle current through the stator and hold the rotating element in the stationary position, we can obtain 60 cycles from the rotor. By making certain changes in the winding of the rotating element we can also obtain any desired voltage. Under normal conditions, when the motor is operating at synchronous or no-load speed, there is practically no frequency

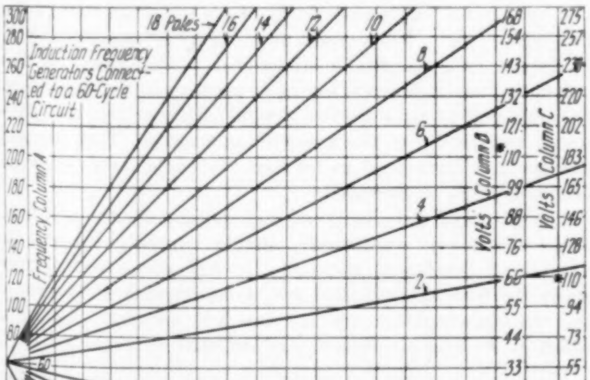


FIG. 4 CHART SHOWING SPEED AT WHICH A GIVEN ROTOR TYPE OF INDUCTION MOTOR MUST BE DRIVEN IN ORDER TO OBTAIN A GIVEN FREQUENCY

generated in the rotor circuit. Therefore, if the rotor is revolved in the opposite direction from which it would revolve as a motor, there will be generated in the rotating element a frequency above 60 cycles, and a certain voltage, depending upon the speed.

Fig. 4 shows at what speed a given rotor type of induction motor, revolving in the opposite direction, will have to be driven in order to obtain any given frequency. As an example, assume that it is desirable to obtain 120 cycles from a 60-cycle circuit. By referring to column A and following the 120-cycle line to the right until it intersects the 4-pole-motor curve, and then dropping down the vertical line which intersects the frequency line at right angles, we find that this motor would have to be driven at 1800 r.p.m. in the opposite direction. Therefore, by using a 4-pole generator direct-connected to a 4-pole, 60-cycle, squirrel-cage motor, a complete motor-generator set for obtaining 120 cycles is obtained.

Again, let us assume that it is desirable to obtain 120 cycles.

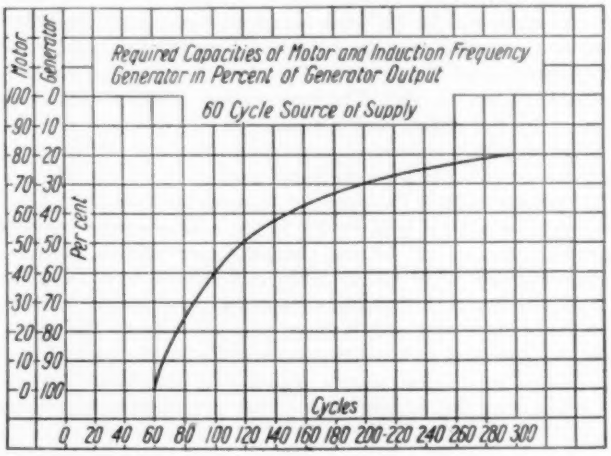


FIG. 5 REQUIRED CAPACITIES OF MOTOR AND INDUCTION FREQUENCY GENERATOR IN PERCENTAGE OF GENERATOR OUTPUT. 60-CYCLE SOURCE OF SUPPLY

It is understood that 1800 r.p.m. is the most desirable speed for driving a squirrel-cage motor operating from a 60-cycle source of supply. Following the 180-cycle line in column A until it intersects the 8-pole curve, and then down the vertical speed line, we find that this machine can also be driven at 1800 r.p.m. The same induction frequency generator could be wound to give 180 cycles at either 99 volts or 165 volts, depending upon the class of service desired. In general, in order to obtain a higher number of cycles the induction frequency generator will require a correspondingly higher number of poles if it is desired to direct-connect it to one of the standard squirrel-cage motors. Hence it may be observed from the curve that a 16-pole, 60-cycle generator would be required to obtain 300 cycles by using the standard 1800-r.p.m., 60-cycle motor.

Fig. 5 shows the comparative sizes of both generator and motor for any kilowatt output. The required capacity of the motor and the induction frequency generator are given in percentages of generator output. For example, assume that it is desired to generate 100 kw. at 120 cycles. Following the 120-cycle line until it intersects the curve, and then on the horizontal line to the left of the intersection, it will be noted that the generator capacity will be 50 per cent and that of the motor, 50 per cent. Consequently in this case the generator will take 50 kw. from the 60-cycle line, the combined sum of the two always equaling the total kilowatt output. Again, assume that it is desired to have a 100-kw. output but at 2000 cycles. Following the 200-cycle line until it intersects the curve and then on the horizontal line to the left, it will be observed that the generator will take 30 kw. from the line and the motor 70 kw.

For any given size of generator the power input is the same irrespective of the kilowatt output at the various frequencies. The kilowatt output from the generator is directly proportional to the increase in speed, and it is necessary for the motor to supply the additional power required to drive the generator at the increased speed. In other words, assume that we have a motor-generator set of 10-kw. output at 120 cycles. As stated above, the power input of this generator from the 60-cycle source of supply will be 50 per cent of the output, or 5 kw. The motor will supply the additional 5 kw. of the output as mechanical power at the generator shaft.

Supposing it is desirable to generate 180 cycles, this same generator will still take 5 kw. from the source of supply, but the kilowatt output will be increased in direct proportion to the speed required to obtain the 180 cycles, or by referring to the curve, it will be found that the excitation of the generator at this point of the curve will be $33^1/_3$ per cent, the motor supplying $66^2/_3$ per cent. In this case the excitation from the line is 5 kw. or $33^1/_3$ per cent of the output. Therefore the output of the machine is 15 kw. It should be remembered, however, that these figures are theoretical, and in practice it will be found that the output will vary somewhat, depending upon the efficiencies of the driving motor and the generator itself.

If by any chance the operator happens to have only direct current available, it is necessary to use a direct-current motor-generator set, and in this case the generator would be of the alternating type. The motor-generator set would have the same characteristics as the induction-frequency-generator set; that is, the generator output will increase proportionally to the speed, but it is necessary to increase the size of the motor to supply the additional mechanical energy required at the higher speeds.

In the event that it is desired to obtain two different frequencies with the alternating current available, it is necessary to use a two-speed alternating-current motor. As an example, assume that 180 cycles and 120 cycles are desired. From Fig. 3 we note that by using a standard 1800-r.p.m. 60-cycle motor, an 8-pole generator will be required to generate 180 cycles. The same curve shows that the 8-pole generator will have to be driven at 900 r.p.m. in order to generate 120 cycles. By referring to Fig. 2, it will be found that with a 60-cycle source of supply, a 4-pole and 8-pole motor would be necessary to obtain 1800 and 900 r.p.m. This pole combination can be taken care of on a single squirrel-cage motor. Such motors can be designed for combinations of 2 and 4 poles, 4 and 8 poles, and 6 and 12 poles, to give the two different speeds required.

In some cases the standard 60-cycle control may be used on the higher frequencies without any change whatsoever. However, the electrical manufacturer should be told of this change to ascertain whether the various parts may be used for the higher frequencies. The same general principles of control will apply to the motors operating on the higher frequencies as those used on 60-cycle service.

It can readily be appreciated that with a combination of the induction frequency generator and the various pole combinations on the motor, a range of speed for any particular type of machine may be obtained.

## Discussion

C. FAIR.[2] Engineers who have kept in close touch with electrical developments for industrial purposes will agree with the author that the electrical industry has "kept pace with the progress of woodworking machine-tool development." It is, however, not so evident that either the woodworking-machinery manufacturer or the woodworking industry as a whole has shown any very marked tendency, until recently, toward taking advantage of these developments. In the last few years competition has become so keen in the wood industry that it has brought about many new developments in woodworking machinery as well as changes in existing tools.

The design of many of the newer machines depends largely upon the direct-connected or built-in motor obtainable for practically any speed required.

It is interesting to note the influence of the electric motor in machine development. At first the motor was used merely as a means of breaking up that type of long-distance lineshaft drive where the shafts were driven from one to another, from building to building, and from floor to floor. From the very beginning it was found that the breaking-up of long lineshaft transmissions resulted in a saving of power sometimes as much as 60 to 80 per cent. Because of the great saving in power due to breaking up long mechanical transmissions the saving of power was looked upon as the principal advantage of the electric drive.

Short shafts driven by motors or group drives were advantageous because they allowed a better grouping or arrangement of tools, irrespective of the location of the main lineshaft.

Individual drives at first were found advantageous principally for large tools remotely located. As the demand grew for larger tools the individual motor drive became a necessity partly because of the advantages of the adjustable-speed motors, partly because of the necessity of placing them where they could be better served by cranes, and partly because of the power required to drive them.

For some time, however, the saving in power cost has been looked upon as a small part of the saving in productive cost, since the power cost for the majority of industrial plants falls within $1^1/_2$ to 3 per cent. The saving of 50 per cent of power cost would mean an actual saving of $^3/_4$ to $1^1/_2$ per cent of the productive cost. Labor costs are roughly 50 per cent of the productive cost, therefore a saving of only 15 per cent in labor cost would mean an actual saving of approximately $7^1/_2$ per cent. It is therefore obvious that rapid-producing machines and labor-saving devices are of the greatest importance. The frequency changer and high-speed motor form one of the means by which production can be increased.

The electrical manufacturers, and the manufacturers of high-speed machinery particularly, should carefully consider the merits and benefits of standards for frequencies and voltages above the 60-cycle range and not, as has been done by some of the machine builders, try to establish arbitrary standards which in the long run cannot help but react unfavorably.

[2] Chief Engineer, Baxter D. Whitney & Co., Winchendon, Mass. Mem. A.S.M.E.

# The Pulp and Paper Industry and the Northwest

By C. C. Hockley,[1] Portland, Ore.

*The purpose of this paper is not to disclose the details of any one process, but rather to furnish a glimpse of the industry as a whole, and in particular that part of the industry using wood fiber, and consequently standing timber, with its relation to the Northwest, its present extent of production and consumption, and its hopes for the future.*

*A picture of the continental, and in fact the world production and consumption, is given, together with a glimpse of our population and rate of growth. There is also a short description of the different processes used. In the latter part of the paper a few of the points in a mill where waste occurs are enumerated, and means for avoiding at least part of these wastes are suggested.*

Our first paper mill was built at Philadelphia in 1690, and made paper from rags. As late as the year 1810, while we had 200 mills, they made but 3000 tons of paper per year, of which 500 tons was newsprint.

Canada built her first mill in 1880, but the industry did not develop largely there until after 1900.

In fact, wood pulp has been largely developed as a paper source since the days of the Civil War, and in 1869 we find that while the country had 677 mills they used only 2000 cords of wood during the entire year. So we see that our use and development of wood pulp has been during the last 60 years. Progress has been phenomenal, and it is a matter of public knowledge that wood pulp in some form is now used for the production of newsprint, wrapping paper, glassine paper, explosives, roofing,

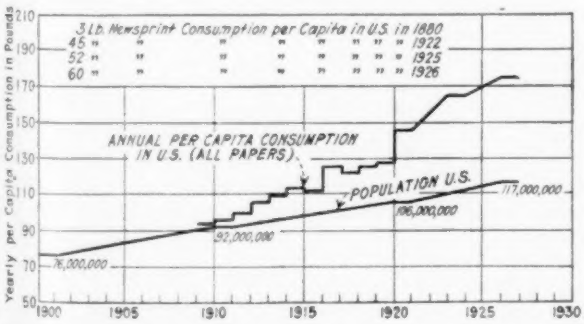


Fig. 1 Yearly Consumption of Papers per Capita in the United States

clothing, imitation silks (Rayon), wall board, car wheels, paints, etc.

A study of the consumption of papers of different kinds in different sections of the country reveals some interesting conditions, such as the fact that newsprint is consumed in quantities varying with the literacy of the population. Also, general paper consumption will vary with the volume of industry and its resulting use of wrappings and advertising.

These facts give the West Coast a high cons mption per capita, due to the high percentage of English-speaking people and high educational standards.

[1] Consulting Engineer.

Contributed by Oregon Section and presented at the Seattle Meeting, Seattle, Wash., August 29 to 31, 1927, of The American Society of Mechanical Engineers.

## Population

In 1930 we may estimate the population of our continent as 140,000,000. This has been a growth in the United States from 38,000,000 in 1870, when our wood-pulp era may be said to have started, to 75,000,000 in 1900, when Canada began to contribute pulp, and to 115,000,000 in 1925, when Newfoundland began its larger developments.

Alaska has reached the day of its development, as has British

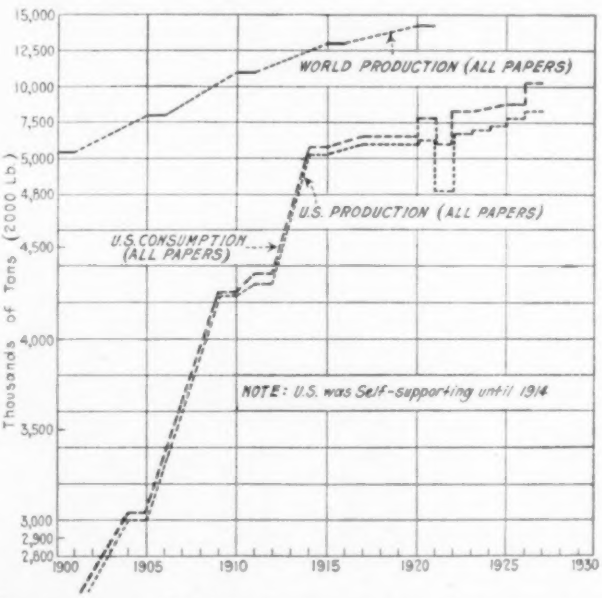


Fig. 2 Curves Showing Production and Consumption of Papers in the United States

Columbia and our Western States, and this last frontier will by 1930 be contributing paper to our continental population of 140,000,000. To complete the picture of our populations, and therefore our users of paper, we must remember that the world looks to us for its future supply, and while we will have about 140,000,000 population on this continent the world population will be about 1,750,000,000, and we find that our continent with 8 per cent of the world's population is and will be using over 50 per cent of its production. (See Figs. 1, 2, and 3.)

While estimates are but guides, at best, it seems logical to assume that the other 92 per cent of the world's population, outside of North America, will later on demand more paper of all kinds than we can supply.

## Consumption

The people of the United States are the world's best customers at present, and in 1926 our consumption of over 10 million tons of paper products gave us the staggering consumption of 175 pounds per capita, while of newsprint alone we used 3,500,000 tons in 1926, or about 60 pounds per capita.

But these high consumptions of paper are not general throughout the world as we may see by the following figures, and while we, as users of all kinds of paper, consume about 175 pounds per year per capita in the United States, Great Britain uses only

about 80 pounds, Germany 45, and Russia 5 pounds per capita.

Fig. 1 shows our increase in annual per capita consumption of all kinds of paper from 75 pounds in 1900 to 175 pounds in 1926. An increase in newsprint consumption from 3 pounds per capita in 1880 to 60 pounds in 1926 indicates a growing consumption per capita, and we would surely be conservative if we assumed the present rate of consumption for future estimates.

### Production

But what has taken place in the way of production during these mad years of climbing consumption?

The United States staggered along until about 1913 with a newsprint production equaling her consumption and then, with our first realization of wasted forests and scarcity of raw material in the East, Canada came to the rescue and we find that, while the United States' production of newsprint has increased from 1,300,000 tons in 1913 to only 1,600,000 tons in 1926, Canada's production has increased from 300,000 tons in 1913 to almost

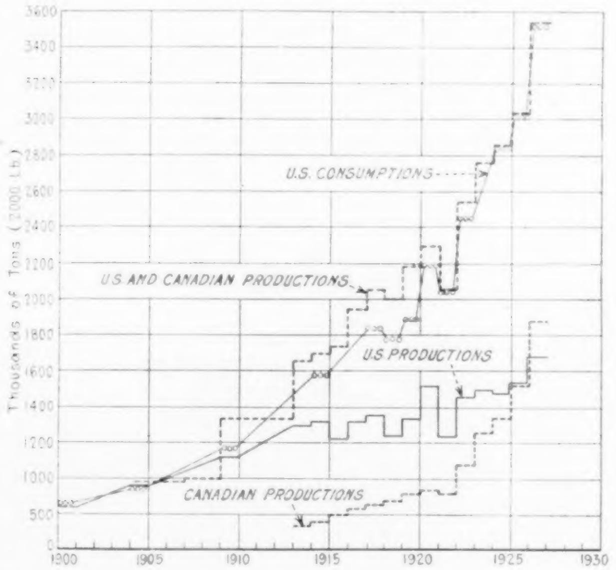


Fig. 3 Curves Showing Newsprint Production in the United States

1,900,000 tons in 1926, and the entire production of both countries has practically all been consumed on this continent. (See Figs. 1, 2, and 3.)

Our continental productions of newsprint for February, 1927, as reported by Trade Associations, confirms the figures given above and were as follows:

| | |
|---|---|
| Canada | 150,773 tons |
| U. S. A. | 121,318 tons |
| Newfoundland | 14,250 tons |
| Mexico | 1,250 tons |
| Total | 287,591 tons |

A study of the charts, which show population, per capita consumption, and production may answer some of the questions as to over-production, and we find that our difficulty in the future is going to be to keep up to consumption, without sacrificing our forests, and our final hopes are reforestation and fire protection—subjects too big to more than mention here.

### Trade Area

Fig. 4 shows an estimated population, in the Western States, for the year 1930 (based upon the increase in population from 1900 to 1920), while the shaded area shows the territory which is competitive or advantageous and reached by either rail or water from pulp and paper mills in the Northwest.

To the population of 17,000,000 in 1930 in the twelve States which are the legitimate trade territory of the Northwest, one must add an estimated population of British Columbia and Alaska of 1,000,000, making a total of 18,000,000, and Secretary Hoover in a San Francisco address predicted that the year 1950 would find a population of 30,000,000 west of the Rockies.

The East Coast is reached by a water freight rate which makes it competitive territory, and the Orient offers the Northwest the untouched and undeveloped hordes comprising half of the world's population—all looking to us for future supply.


Fig. 4 Population and Trade Areas as Estimated for 1930—Shaded Area Indicates Territory Which Is Competitive or Advantageous

This population in our Western trade territory (18,000,000) gives us an estimated consumption of 1,500,000 tons of all kinds of paper in 1930, as against a consumption of 1,200,000 tons in 1926.

There are 41 mills in Washington and Oregon making an annual production of 1,000,000 tons of pulp and 800,000 tons of paper and board.

This means that by 1930, without going either to the East Coast or to the Orient, we will be able to sell on the West Coast an additional 700,000 tons of paper per year, or 2335 tons per day.

In addition, we have still open, as legitimate markets for our products, the Southern and Eastern ports, on at least a competitive basis, and the Orient with favorable freights from the Northwest.

### Pulp Wood

The following figures taken from Government sources are essential to an understanding of our raw-material supply:

It is estimated that our original stand of merchantable timber was about 5250 billion board feet in the United States, of which 2750 billion remains (1250 billion west of the Rocky Mountains).

In addition to the above merchantable timber figures it is estimated that on the continent we have about 1750 billion board feet of timber (without using any of the waste from the merchantable timber) suitable for pulp. This would give us about 2500 million cords, but as much is inaccessible, and as it is an estimate only, we should not use a figure of over 2000 million cords, and a very conservative estimate reduces this amount to as low as 1000 million cords. As the United States used in 1926 about 10 million cords, we have an apparent wood supply for 100 years at our present rate of consumption, and without considering increased population, increased per capita consumption, or any new use or export business.

We should not, however, feel that wastes can continue, and should learn a lesson from our experience in the Eastern part of

the United States where the one time "boundless forests" have almost disappeared.

A sound reforestation plan is our only safe program.

The hysterical statements which indicate a boundless supply of wood, as well as an attitude which would not allow full production to the limit of our ability to consume, should be avoided.

Just a word as to our pulp wood supply in the Northwest, and still leaving out the wastes from merchantable stands:

| | |
|---|---|
| British Columbia has about | 42 million cords |
| Alaska, which may be considered as all pulp wood, about | 100 million cords |
| United States, west of Rockies, about | 500 million cords |
| Total | 642 million cords |

This supply can take care of our entire continental consumption on our present basis for 60 years, and would be a perpetual supply, if reforested.

### Economics

In a study of the economics of our situation we need not be frightened by talk of freight rates, cost of wood, costs of power, sales costs, etc., because it is after all not a question of the cost of any one item which will decide the result as to profit and loss but is the sum total of costs of the product delivered to the consumer, and in this respect the Northwest stands in a position second to none.

This completes our survey of available wood, possible markets and our Northwest's possible share in the industry's development, and the facts stated indicate that we have the opportunity to meet a world need in production; that we need not fear overproduction; and that we are in an economically sound position, but with each individual mill having its own problems to solve.

### Processes

As in the preceding paragraphs of this paper, the discussion will be limited to those processes using wood as their raw material, and such valuable pulp sources as straw, rags, bagasse, cane, etc., will not receive treatment.

With small variations we find that practically all of the wood pulp is made by one of the four following processes:

1 Ground wood or mechanical process
2 Sulphite process
3 Soda process
4 Sulphate process

Fibers, as made by any one of the above processes, may be combined and formed into a sheet of paper, the quality of which will depend upon either the species of wood used, or the degree of refinement used in its manufacture.

*Mechanical Pulp* is so called because it is produced by holding the log or block under pressure against a revolving grindstone. The stone tears the fibers from the block and the result is "ground wood." Fig. 5 illustrates one type of grinder used for this work. Mixed with water, the fibers are screened and refined and form the basis of newsprint paper (75 to 85 per cent) and also the bulk of boards and papers requiring no particular strength or fineness of texture.

*Sulphite Process.* This process is a combination of mechanical and chemical treatment of wood, the block or log being reduced to as nearly a uniform chip as possible, these chips then being treated or cooked in a closed digester under steam pressure.

The solvents, with which the chips are "cooked" are a bisulphite of lime and sulphurous acid, and, following the cooking, the dissolved matter as well as the solvents are washed out, leaving the fiber only.

No recovery of the chemicals is made by this process, except that of the gases which are relieved during the cooking process.

The same screening and refining of the pulp is used in this process as in making mechanical pulp.

*Soda Process.* This process differs from the sulphite process principally in its use of an alkali (soda) as a solvent and in the recovery of its chemicals by a system of evaporating, burning, and leaching.

*Sulphate or Kraft Process.* Like the soda process, this is a combination process. Chips and a solvent of sodium sulphate (salt cake) are employed, and this process also has an elaborate recovery system for reclaiming its chemicals.

Any one of the processes, or their modifications, will make a fiber, and the choice of process will depend upon the species of wood available, power available, kind of paper or pulp desired, etc.

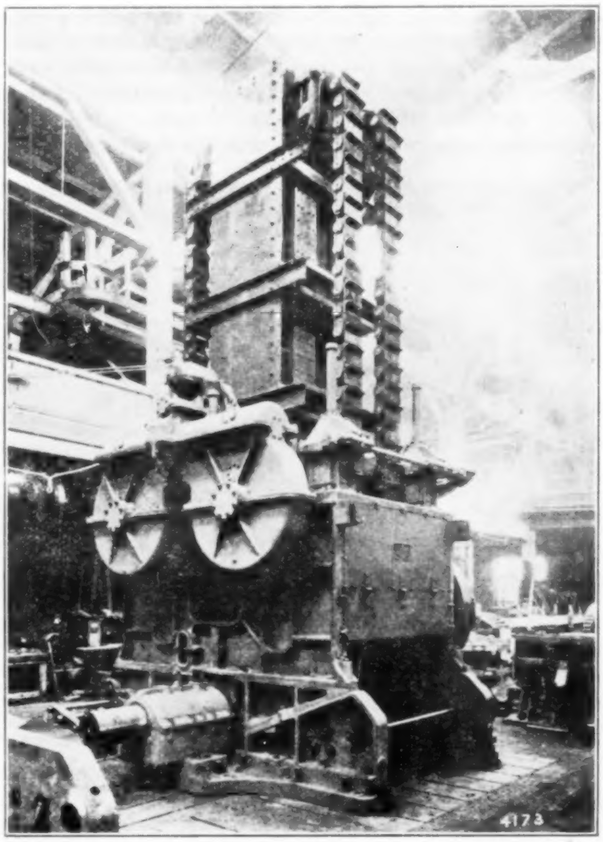

Fig. 5 Magazine Grinder Used in the Production of Mechanical Pulp

From the standpoint of yield per cord, the mechanical process produces more wood pulp, as it merely uses the entire block, shredded, while any chemical process, although giving a longer and stronger fiber, loses all of the dissolved material and produces only about one half as much wood pulp per cord.

### Wastes and How to Avoid or Remedy Some of Them

The discussion of wastes in a manufacturing industry often leaves out of consideration the losses or wastes which result in failure of the concern. Before taking up the losses of fiber in the pulp and paper industry the author would mention the losses due to management, incorrect design, and equipment. A proper cost system would doubtless reveal most of the following, which for lack of a better name may be termed general losses:

*General Losses.* Low production often occurs as a result of bad design, poor construction, unbalanced equipment, or breakdowns, and generally a large proportion of the manufacturing costs continue regardless of magnitude of production. As an example, a sulphite-pulp mill with a capacity of 40 tons per day produces but 30 tons. Its cost per ton at the mill is, say, 36 dollars, of which the raw material will amount to 16 dollars, leaving a balance of 20 dollars per ton, which in the case of 40-ton production would decrease to 15 dollars. In other words, 5 dollars per ton has been wasted in administration, taxes, depreciation, labor, etc.

*Labor.* During periods of low production, labor is wasted. In well-run newsprint mills the labor required will run down as low as about one man per day ton, but in many cases two or more men per day ton are required. This is an economic waste, since surely our prosperity depends upon the largest production, of good quality, possible per man.

Turnover costs are difficult to ascertain, and whether replacement costs 25 or 500 dollars per man will never definitely be known, although it cannot be doubted that it is an expense and results in decreased production.

FIG. 6 TUMBLING BARRELS, OR BARKING DRUMS

The outstanding reasons for the use of fewer men are:

(*a*) Improved design of mills, with consequent proper routing of processes and materials. A good example is the use now of pulp, in the paper mills, in what is known as "slop" form. This means the saving of pulp machinery, as well as men formerly engaged in forming the screened pulp into "laps," storing and handling the laps, and then again reducing the laps to "slop" form at the paper mill. As the screened stock contains but one-half to one per cent fiber, the water must be removed in order to form the "laps." This is done by a partially submerged wire-screen cylinder revolving in a vat of the screened pulp. The water escapes through the screen (taking with it some of the finer fibers), and leaves a coating of fibers on the cylinder. This fiber is removed, pressed, and folded into "laps."

(*b*) Advancement in the design and capacities of machinery has reduced man power per ton, as is shown in the following cases: "Barking drums" (Fig. 6) replacing knife barkers have in many cases reduced the men required in the wood-preparing rc m by 50 per cent. Magazine grinders of large capacity also have reduced the number of men required, as they require no more attention than the smaller types.

The modern paper machine, with its width of as much as 284 in., as compared with the 120-in. width of 15 years ago, and its speed of as much as 1500 ft. per min., as compared with 300 ft. per min. 15 years ago, has boosted the output from 25 tons of paper per day to from 125 to 150 tons per day—all with the same labor.

*Design.* Aside from the question as to whether or not the mill location is an economic one, the number and size of units used, the layout and arrangement of the different departments, the synchronization of the different processes, and the handling of material, all will contribute to the success or failure of the project, and correct design will assist in eliminating the wastes of both construction and operation. Time for study before building, a step too often hurried, is as important as any one step in the development of this industry.

*Power.* Power losses assume a conspicuous place in the survey of wastes, due to the fact that they are so large a proportion of total costs of manufacture (15 to 25 per cent), but often they are not realized, and in many cases are hard to locate or compute. An example of this difficulty is the existing cases of a pulp-and-paper mill which generates its own steam power in two different boiler houses; generates electrical energy in one of the boiler houses; generates energy by means of water wheels direct connected to machinery, and purchases electrical energy from a local public utility. To complicate the problem, the purchased as well as the generated electrical energy is used in both plants, and on occasions the power generated acts as a stand-by service for the utility company. The correct distribution and the correct charge for power are almost impossible of solution, and the engineer in the larger boiler house may perhaps be forgiven for reporting an efficiency of 108 per cent when it is discovered that he uses as fuel both coal and wood-room refuse, neither of which is weighed or analyzed as used.

The day has arrived for public utilities, and is fast approaching for pulp and paper mills, when efficiency will be the order in the power department and the wastes will be the criterion by which the success of the company may be gaged.

The losses due to incorrect design or construction of furnaces are not only reflected in the repair bill but result in either the wastes of an excessive flue gas temperature or a high carbon content of the ash.

Money expended for soot blowers is not a waste if they save fuel or avoid shutdowns, nor is the outlay for superheaters or better boilers if they result in higher efficiencies, lower repair bills, and possibly the generation of sufficient power with the cost of both steam and electrical energy reduced. High pressures and superheat permit high-pressure turbines to exhaust into low-pressure mains and digesters. A higher cost per steam-generating unit results, but there is a saving in the number of units, amount of labor, repairs, power costs, etc.

Failure to provide for a system returning all condensate to the boiler house results in the use of more makeup water, more fuel and more labor, which is truly a waste. Proper insulation of steam lines and digester, although much discussed, rarely is completely achieved. The cost of lubricants does not represent the only waste due to the use of poorly designed drives, poor bearings, etc.; again more labor, shutdowns, and more power result. The purchase of bearings by price and size results in waste.

The practice of driving many machines from one line shaft results in waste, as there is usually continuous operation of part of the equipment, and a loss of power, excess consumption of lubricant, extra labor, etc., accompany the maintenance of the line-shaft equipment.

*Fiber Wastes.* Since wood-pulp costs and consequent paper costs are made up largely (15 to 50 per cent) of the cost of wood, considerable time and study should be given to avoiding its waste. For the purpose of this paper, the problem will be taken up at the wood-preparation department, and will not consider the statements, perhaps hysterical, of wastes in logging operation.

One cannot expect to use black knots or rot in pulp; therefore, there will always be an apparent loss from this source, because all such defects must be cut out, and the operation always carries with it the discard of a certain amount of the good fiber. This waste, however, may be reduced to a minimum through care on the part of the knife barkers, and by using barking drums where possible. It is now history that the tumbling barrel or barking drum reduces the waste from about 20 per cent to 6 per cent. This figure applies to small wood as found in Eastern Canada, and will not be accurate for larger woods. The waste material from the above operation is burned, but the heat value is barely sufficient in most cases to consume the refuse, due to moisture in the bark, and certainly the good wood sacrificed is a total waste. This waste has resulted in the development of bark presses which squeeze out the water and leave the bark with a possible fuel value above that needed to evaporate the water contained. The correct solution of this problem is to reduce the 20 per cent to about 6 per cent, and burn or waste only the bark and such knots or rot as have no fiber.

Logs received at the mill weigh, or at least the railroads charge for a weight of, 7500 lb. per thousand board ft. log scale.

It is generally considered that one board foot log scale weighs about 7500 lb. and this is finally resolved into the following figures:

| | |
|---|---|
| Lumber | 3700 lb. |
| Sawdust | 2300 lb. |
| Refuse: | |
| (a) Bark | 750 lb. |
| (b) Waste Wood | 750 lb. |
| Total | 7500 lb. |

This may be assumed to give, where large Western woods are used, a weight of 6000 lb. as prepared for the pulp mills; an amount equal to about 1.6 cords, not considering the waste wood or bark.

This figure also compares with the average weight of 3800 lb. of a prepared cord of wood in Eastern Canada or Eastern United States. But it is found that one cord of prepared wood (3800 lb.) per ton (2000 lb.) of ground wood is required, and roughly two cords of prepared wood per ton of chemical fiber. It cannot all be waste, but what has become of the 1800 lb. of prepared wood which disappears in making a ton of mechanical pulp, and the 5600 lb. which disappeared in making a ton of chemical pulp? The following may be considered:

(a) Moisture will make up perhaps 30 per cent of the total weight of wood having a dry weight of 2660 lb. per prepared cord. Also, there is a loss in making a ton of ground wood of 660 lb., or 33 per cent, all of which is either lost in slivers, sawdust, or in the fibers lost in the white water.

(b) Of the two cords used in making a ton of sulphite there would remain, after deducting 30 per cent moisture, a weight of 5320 lb. of dry wood, and from this is finally secured 2000 lb. dry weight of chemical pulp.

Chemical analysis, however, shows that only about 50 per cent of the weight of most species of wood is cellulose so 50 per cent may safely be eliminated except for the recovery of by-products.

Deducting matter other than cellulose there remains 2660 lb., and from this is produced but 2000 lb. of chemical pulp or cellulose. Again there is a loss of 33 per cent during the process of manufacture. The operations causing a part of this loss will be mentioned.

*Wood-Preparation Losses.* In making the chips, unless the knives be kept sharp, slivers are made which are either thrown out or, if cooked in the digester with the uniform chips, are not reduced to fiber and pass to waste as screenings. Slivers may account for as much as 2 per cent of the prepared wood. Sawdust made in the preparation of the chips will amount to about 3 per cent of the weight of the prepared wood, and much more will be wasted if the knives and crushers are not kept in condition. This is all waste, except for possible fuel value. It is notoriously true that slivers are hard to refine, and the tendency is to burn them or dump them in the stream and hope that they will disappear.

*Grinding Losses.* In the mechanical-pulp process the nature of the grinding and the variation in the character of the wood makes it impossible to avoid the production of slivers. The quantity may, however, be reduced by attention to the surfacing of the grinder stones, careful regulation of the pressure, and care in keeping the pockets of the grinders filled.

The character of the wood also affects the amount of slivers

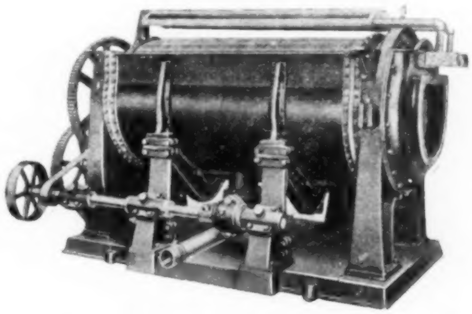

Fig. 7 Type of Filtration Apparatus Designed to Eliminate Waste

from a chemical cook, although care in the preparation and uniformity of the chips have much to do with the result.

*Pulp Washing Losses.* After the pulp has left the digesters, in the case of chemical pulp, and before screening, it must be washed and all chemicals removed. At this point large wastes occur as the pulp is drained through perforated plates while being washed with a large amount of fresh water. If the perforations through which the wash water drains be large, or the pulp be forced through by the action of hose or other washing systems, the loss is very great and the escaping fiber is either discharged into the river (sulphite process), or is burned during the recovery of the chemicals (sulphate process).

Waste sulphite liquor will amount to about 2000 gallons per ton of pulp. Attempts to reclaim fiber in the wash liquor from the sulphite process have been made, and by-products such as alcohol, glue or size, tannin and turpentine have been secured. The waste liquors have also been neutralized and the water partially evaporated (Robson process) and the residue used for road binder, or if further experiments so indicate it may be used as fuel.

These efforts at economy are in the early stages of development and are well worth while, but care should be taken to see that the fiber is removed from the wash water by careful maintenance and operation of the blow tanks, diffusers and blow pits.

*Screening Losses.* The pulp from the digesters, like that from the grinders, is screened. It passes first through a knotter, which removes the knots and large slivers, and later through the fine screens which remove the too coarse fibers.

These processes are almost always accompanied by a large loss of the good fiber which adheres to the coarse material, or is carried away in the wash water, and irregular cooking or lack of control of chemicals increases the amount of fiber lost.

The rejected material from these operations is sometimes refined and again screened, but as this fiber usually is discolored or is dirty from the knots and rot, the final answer is the rejection and waste of the major part.

Students of the subject state that the waste of fiber in the white water should not exceed 3 per cent of the weight of pulp nor over 1 per cent of the weight of prepared wood.

*Conversion Losses.* After the stock is screened it is ready for the paper mill. Usually, however, the mill is located elsewhere or is not ready for pulp, in either of which cases the pulp is converted into lap form and stored or shipped. In this process fiber is again lost on the cylinder which removes the water.

With the passing of the pulp to the paper mill it is found that, although there is but one place in which any loss should occur, and although the white water from this source (paper machine wet end) can be used again in the beaters, screens, etc., still there are losses or shrinkage about as follows:

| | |
|---|---|
| Wrapping-paper manufacture | 5 to 10 per cent |
| Newsprint-paper manufacture | 7 to 12 per cent |
| Tissue-paper manufacture | 10 to 15 per cent |
| Book-paper manufacture | 10 to 18 per cent |

The cause of these losses is often the use of surplus water in which fiber is discharged to the sewer with the white water. Save-alls of both the sedimentation and filtration types have been developed to a high state of efficiency (95 to 98 per cent), and they offer a solution for the white-water troubles, as well as a return in dividends. Fig. 7 shows a type of apparatus for this purpose in common use.

The items in which other wastes may occur are of an infinite variety and cannot possibly be mentioned in an article of this kind. We return, therefore, to the best solution of the problem offered to date, namely, the recommendation that time enough be given for careful study before starting the mill and the practice of eternal vigilance in operation.

## Bibliography

The following books, selected from a long list, will give a good start to any one wishing to study pulp and paper manufacture in detail:

The Manufacture of Pulp and Paper, five volumes, prepared by Pulp & Paper Technical Association.
Pulpwood and Wood Pulp in North America, by Kellogg.
Paper Making, by Cross & Bevan.
Modern Pulp and Paper Making, by Witham.
Chemistry of Pulp and Paper Making, by Sutermeister.
Text Book of Cellulose Chemistry, by Heuser, West, and Esselen.

# Lacquer and Varnish Films

## A Study Revealing a Definite Similarity of Failures, Pointing Out the Problems Calling for Research Work and Discussing the Development of a Clear Lacquer to Withstand Outside Exposure on Wood

By PAUL S. KENNEDY,[1] NEWARK, N. J.

IN A PAPER presented at the 1926 Annual Meeting entitled "A Study of Varnish and Lacquer Finishes Exposed to Accelerated Breakdown Tests," the author stated that as some of the results attained were more indicative than conclusive, the investigation would be continued. Accordingly the outstanding points of the work have since been checked and further supplemented by some normal exposures and by practical assistance from wood cabinet manufacturers. As the investigation proceeded some interesting points developed:

1 The ultimate failure of lacquer and varnish films was found to be surprisingly similar. It was positively demonstrated that these failures could be distinctly classified and recognized, and their causes clearly defined.

2 It was found that there was a general lack of understanding among those actually engaged in wood finishing as to the exact causes for these failures, and that it would be desirable to explain any basic similarity between the compounding of varnish and lacquer, and to detail the reasons for failures.

3 The comparative behavior of varnish and lacquer films indicated the desirable qualities to be incorporated in lacquer films, and suggested the lines of research to be pursued in order to overcome existing deficiencies.

4 The failure of clear nitrocellulose films, particularly out of doors, when exposed to the ultra-violet rays of sunlight, suggested the development of a filter for these destructive rays; either by a chemical agent or the development of a base other than nitrocellulose, which would give the desirable drying qualities of lacquer.

5 The failure of all nitrocellulose-base materials on outside exposure on wood suggested the development of a material to meet this condition which would have lacquer-drying qualities.

Most of these topics will be recognized by both the research man and the man of practical experience as worthy of comment. In view of the experience gained by the author through personal interviews, it appears desirable to him to present what follows in a popular rather than a too technical manner, sacrificing absolute accuracy in some cases to the end of a clearer understanding.

### 1 Fracture Failures of Lacquer and Varnish Films

The fracture failures of lacquer and varnish films may be definitely classified as (*a*) cross-checks, or temperature checks, (*b*) humidity cracks, (*c*) plasticizer or overcoating cracks, and (*d*) old-age cracks.

*a*—Cross-checks are caused in lacquer just as they are in varnish—by exposure of the films to a decided drop in temperature. In both types of film these cracks run at right angles to the direction of the grain of the wood. Fig. 1, a typical macrophotographic illustration of this failure, shows this very clearly.

The nature of cross-checks in lacquer varies with its flexibility. The more flexible the lacquer, the wider and deeper the cross-checks. The less flexible or "more gummy" the lacquer, the more closely they approximate the typical "hairline" varnish temperature crack.

A temperature crack on a lacquer film remains permanently visible. With certain types of varnish, temperature cracks apparently close up again when normal temperature is restored.

*b*—Humidity cracks are just as definite in their formation as temperature cracks. They are caused by a swelling force of the wood sufficient to break the film, and the fracture is always directly with the grain of the wood. Once a lacquer film is fractured with a humidity crack it remains as a permanent defect. With certain types of varnish such cracks often apparently close up again, when the swelling of the wood abates.

Two very excellent examples of humidity cracks are shown in the accompanying macrophotographic illustrations. One failure occurred on a straight-grained wood panel (Fig. 2); the other, on an oval-shaped grain (Fig. 3). It will be noted that in both cases the cracks follow the contour of the grain.

*c*—Plasticizer cracks, as they are termed by the lacquer specialist, or overcoating cracks, as they are designated by one familiar with varnish, are caused by a condition of case-hardening of the film. The softer underneath portion of the film exerts a pressure on the crusty top surface, which finally fractures it.

This crack is typical and resembles a hook, or a hairpin with one side broken. After the initial failure the defection continues and the hooks join up, so that in many cases a replica of a popular type of metal paper clip is reproduced. Figs. 4 and 5 show, respectively, this type of crack in its first stage and in its fully developed state.

*d*—Old-age cracks are, as their name indicates, the ultimate deterioration of a film through the simple process of wearing out. They are found more frequently with varnish than with lacquer, and while they resemble overcoating cracks to some extent, they are generally much smaller and more rounding and their inception is usually in a "crow-foot" formation. Fig. 6 is a typical illustration of the old-age crack.

### 2 Basic Similarity of Lacquer and Varnish

Basically speaking, lacquer and varnish are surprisingly similar in the way they are compounded. The popular nitrocellulose type of lacquer is composed principally of soluble cotton, gums, thinners, and plasticizers, while varnish is composed of vegetable drying oils, gums, thinners, and driers.

The plasticizer content of lacquer and the drier content of varnish can be eliminated from the consideration of the film in general, because both are present in minor amounts for incidental purposes.

A plasticizer is usually a non-evaporative liquid, which is a common solvent for gums and cotton, and its purpose is to maintain a lasting union between these two ingredients; while at the same time imparting a certain amount of elasticity to the film.

The driers in varnish are usually compounds of lead, manganese, or cobalt, and their purpose is to hasten drying by stimulating the oxidation of the oils.

Both lacquer and varnish contain thinners. Admittedly these thinners differ in their chemical composition but upon exposure to the air, in both cases, they should evaporate cleanly. Obviously they can be eliminated from any consideration of the resultant film in which we are interested.

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Presented at the National Meeting of the A.S.M.E. Wood Industries Division, Grand Rapids, Mich., October 17 and 18, 1927.

The next point in common is that both materials contain gums. These gums may vary in their constitution, but their purpose is identical. In each case they are used only to give hardness, fullness, and luster. The higher the gum content in a varnish, the better its luster and fullness, and the more brittle its film. The same is true for a lacquer film.

how a material which dries so rapidly can be flexible or durable. The answer, of course, is that it is the chemical nature of nitrocellulose to have these qualities when properly deposited in a film, and that this can be accomplished simply by the evaporation of its solvents.

The physical nature of ultimate varnish and lacquer films,

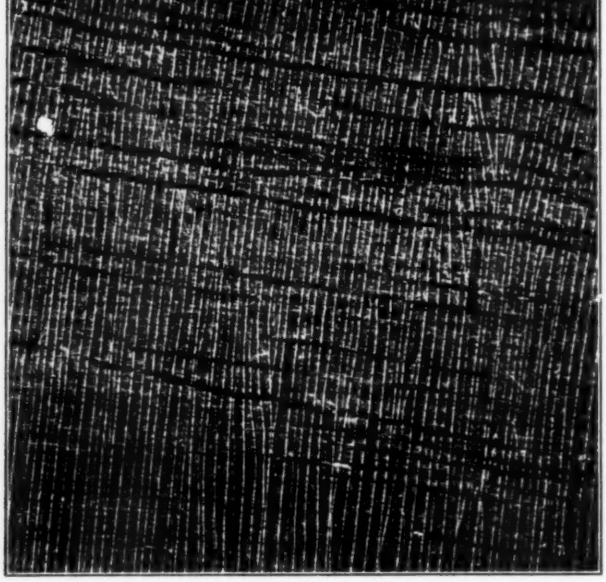

Fig. 1 Macrophotograph Typical of Cross-Checks or Temperature Cracks on Varnish and on Easy-Rubbing Types of Lacquer

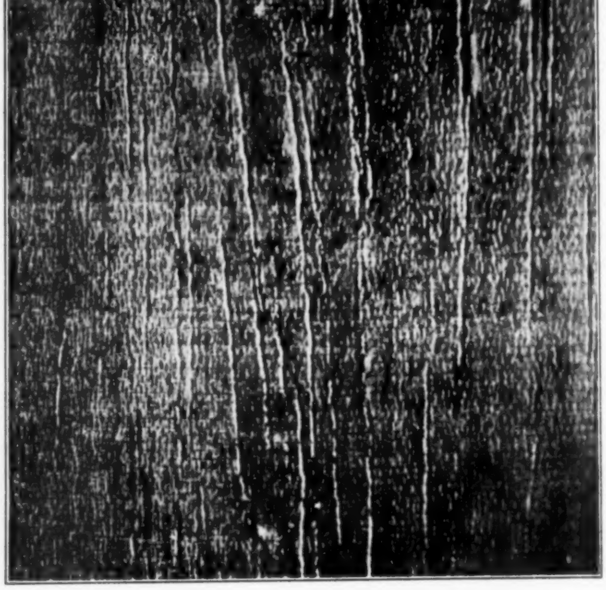

Fig. 2 Macrophotograph of a Lacquer Film Typical of Humidity Checks on Straight-Grained Wood

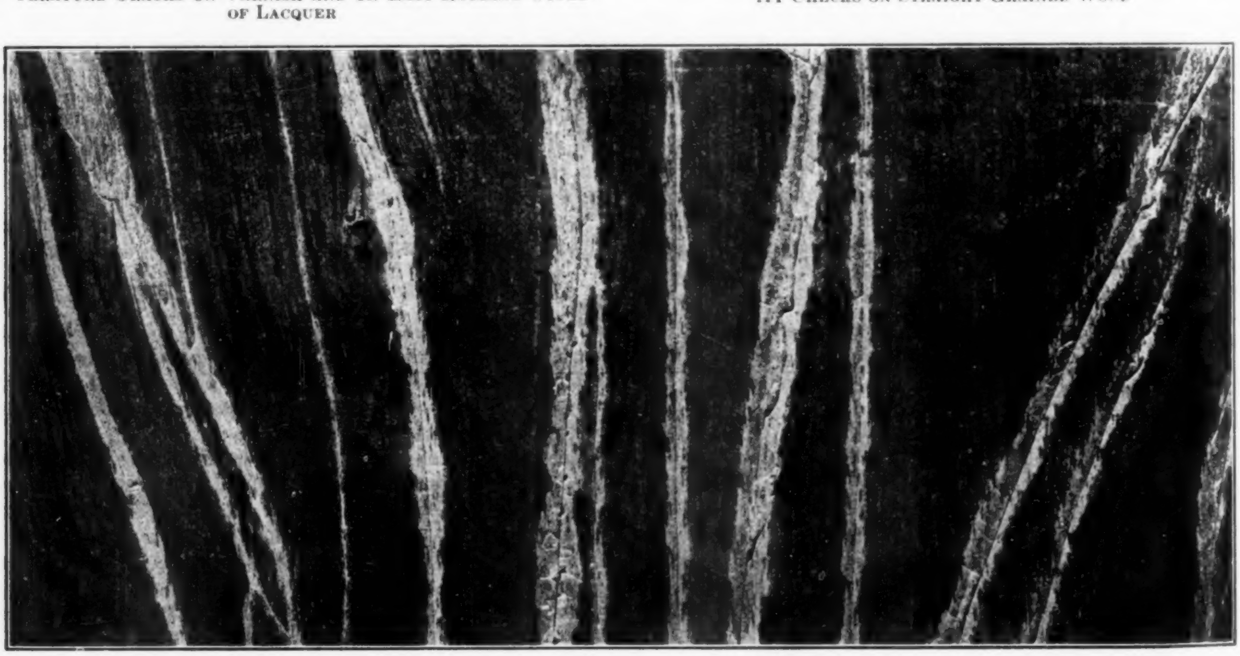

Fig. 3 Photograph of Humidity Cracks on Comb-Grained Wood Showing How Fracture Conforms with the Grain of the Wood

Hence the only basic difference between a varnish and lacquer film is that the varnish gets its elasticity from an oil which must undergo a time reaction of oxidation to produce desirable hardness; whereas lacquer obtains it from nitrocellulose which only requires the evaporation of the thinners in order to harden.

Many old-time varnish users will bring up the question as to

however, is a very vital point. A crude explanation would be that varnish dries to a "plastic" film; whereas lacquer dries to a "tight" film resembling a drum head.

Under normal conditions, a varnish film will "live" as long as it can consume oxygen. The drying of varnish is a phenomenon of combustion. As long as the oil is unsaturated or still able to

absorb oxygen, life remains. When it can no longer absorb oxygen its plasticity disappears, because it literally "burns up," and then deterioration sets in. When a lacquer film "sets" it is, to all practical purposes, dry. Actually, there is a residue of solvents in the film which gradually dissipate as the film ages. This brings up a vital point.

As oil dries it increases in weight, by the simple absorption of oxygen, and a "live" varnish film can be said to be always increasing in volume as long as it can absorb oxygen. Conversely, a lacquer film is constantly decreasing in volume, or "tightening up."

A lacquer film is much tougher, or stronger than a varnish film. If pressure is exerted on a varnish film its impulse is to yield to such force, and continue to do so up to the limit of its flexibility. On the other hand, a lacquer film will resist, and continue to do so until fractured.

With these distinctions in mind we can consider the four fracture failures previously mentioned more understandingly.

*Cross-Checks or Temperature Cracks.* Wood is quite unique in its behavior toward temperature change. Although it expands and contracts across the grain, it is immovable or stationary with the grain. When a wood surface coated with a film of finishing material is exposed to a radical drop in temperature, the film of course contracts in all directions. Across the grain the wood moves in harmony with the film; but longitudinally we have the condition of a moving film cemented on an immovable surface. If the contraction is severe enough the film must break. This is why the fracture is so clean across the grain of the wood.

As indicated in the previous explanation, when this action starts varnish yields readily, because of its plasticity, and if it be a fairly elastic type it has resilience enough, when the temperature again becomes normal, to return to its former state as far as the eye can see. The tight, resistant lacquer film is ruined, however, for it remains as a permanently visible defect.

*Humidity Cracks.* Wood is sensitive to atmospheric changes and has somewhat the nature of a sponge in its thirst for moisture at certain periods of the year. Spanning the cold, dry days of winter and the hot, humid days of summer, it is not unusual for wood to vary in moisture content from 5 to 16 per cent.

When wood is first finished, it is desirable to have its moisture content as normally low as possible. When it is able to absorb, say, 10 per cent additional moisture, the result is of course a proportionate increase in weight and volume. This results in swelling, and the movement is across the grain of the wood.

In the case of open-grained woods the "high-lights" push themselves upward, and this gives the illusion that the finishing material is sinking into the pores. It is common among finishing-material users to misunderstand this, at such time that the finishing material is "shrinking" on their work. The action is really the opposite of shrinking, and if the pushing up and outward force of the wood is sufficient to strain the finishing film, it will be fractured. Of course in this case the crack must be directly with the grain of the wood. Just as in the case of "cold-checking," the varnish film yields to this force almost at once, and even if finally fractured, in many cases, apparently "closes up" later on.

A lacquer film resists very strongly, but if the force is sufficient it snaps beyond recovery.

*Plasticizer or Overcoating Cracks.* The term "overcoating cracks" has been handed down from the old days of varnish, when linseed oil was the only drying oil available, and varnishes were very heavy-bodied and strongly charged with metallic driers.

If the varnish worker was not careful or was too lazy to brush out these hard-working varnishes, it was comparatively simple to apply such a thickness of film on the work that it would dry sufficiently hard on the top of the film to exclude oxygen from the underneath portion. The under part of the film would thus be in a more or less mushy state. As time went on, particularly with temperature changes, this difference in elasticity between the soft under portion of the film and the crusty upper surface eventually had to result in the cracking of the top surface.

With the advent of China wood oil this possibility of overcoating cracks was further increased, because it is the natural tendency of this oil to dry very rapidly and at the point of least resistance, namely, the upper surface, where the supply of oxygen is most available. This tendency of China wood oil is taken advantage of in making the so-called "crystal" or "alligator" finishes in common use on optical, radio, and electrical instruments. This commercial finish is a typical example of true overcoating cracks.

When these failures occur in lacquer they are called plasticizer cracks. Their cause is exactly the same as with varnish, i.e., the film has dried harder on the top than it has underneath. As explained above, a plasticizer is often a non-evaporative or non-drying liquid; and if a lacquer is not properly formulated, the use of an over-balanced amount of this ingredient leaves a softness underneath the top of the hardened film which must eventually result in checking upon continued exposure to heat.

*Old-Age Cracks.* These need little explanation. In the case of varnish, the complete oxidation of the oil renders the film no longer resistant to moderate torsion. In the case of lacquer it practically means inability to contract further, or a tightening down of the film.

### 3 Desirable Qualities to Incorporate in Lacquer Films

From the practical user's standpoint it would be desirable to remedy the deficient "bodying-up" or "building" properties of lacquer as compared with varnish; further, it would be obviously desirable to incorporate more of the plastic nature of a varnish film in a lacquer film.

Inasmuch as varnish possesses both of these desirable qualities, the logical thing to do would be to endeavor to amalgamate the two in such a manner that the relatively poor plasticity and the poor building qualities of lacquer would be improved by varnish, but at not too great a sacrifice in drying time.

The principal stumbling block to this, however, is the fact that nitrocellulose is antagonistic to unoxidized drying oil. But if the basic ingredient of varnish could, by a preliminary treatment, be rendered compatible or miscible with nitrocellulose, it would be a step toward solution. Through research this has been accomplished, and there is now available a lacquer with building qualities superior to those of high-gum content lacquers and of equal ease of rubbing, plus a highly desirable toughness.

This finish has the objection that it is more sensitive to abnormal conditions than straight nitrocellulose lacquer, and not as adaptable to extreme speed in coating and rubbing, day in and day out. Its dryness and hardness under normal conditions, however, are quite similar, and to all intents and purposes it is quite applicable to anything except extraordinary production schedules.

This type of "varnish-lacquer" occupies an unique position with regard to other fast-drying finishes, for in order to get the same toughness with a straight nitrocellulose lacquer it would be necessary to make a tremendous sacrifice of building qualities and ease of rubbing.

### 4 Synthetic Lacquer Resistant to Ultra-Violet Rays of Sunlight

To the finish manufacturer a "lacquer" is a finishing material which dries quickly to a hard film. Unfortunately, the popular conception of lacquer is that it is a nitrocellulose-base material. The tin decorator has been using varnish materials which bake hard in a few minutes for a great many years, and he has always called them lacquers. Then there are Chinese and Japanese

"lacquers" and also solutions of gums in alcohol which have been termed "lacquers" for years. Obviously none of these contain nitrocellulose. So when the term "lacquer" is now used here, it does not necessarily refer to a material of nitrocellulose base, but rather to almost instantaneous drying qualities.

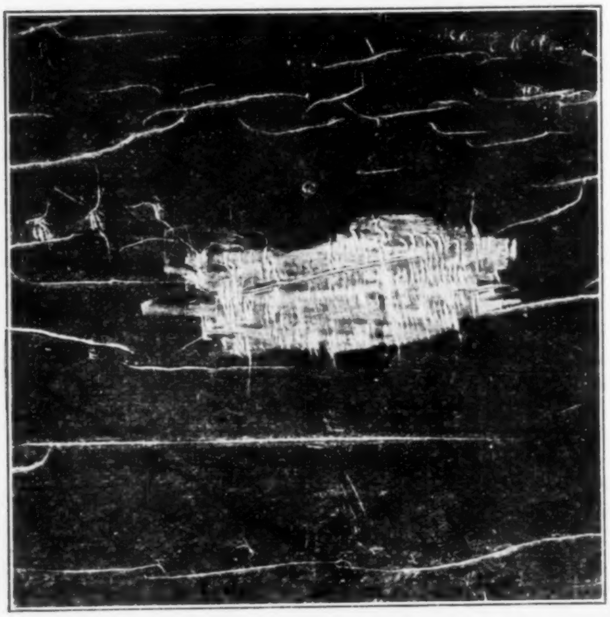

Fig. 4 Overcoating or Plasticizer Checks in Their First Stage—The Hook Check

(The large white section is a place where the film was shaved down to further examine depth of cracks.)

Fig. 5 Overcoating or Plasticizer Checks in Their Finally Developed Stage—The Loop Crack

It is well known that nitrocellulose in the clear form breaks down very rapidly under the ultra-violet rays of sunlight. Window glass is a good filter for ultra-violet rays, so the problem of durability of a clear lacquer film is an out-of-door problem.

There would be three logical solutions for this problem: First, to introduce a soluble chemical into a nitrocellulose film which would act as a filter for the rays. Another would be to partially replace the solid contents with an ingredient which in itself is a good filter, so as to partially reduce the effect. A third would be the production of an entirely foreign basic material which would deposit a satisfactory and durable film not affected by the ultra-violet rays.

Much work has been done on the first-mentioned method, but with very little satisfaction. Aniline-base ingredients have shown some promise, but the better of them discolor the film.

The second method has been employed successfully to some extent by the combination varnish-nitrocellulose type of lacquer previously commented on for wood-cabinet work, but in a more elastic form.

Vegetable oils are ultra-violet-ray filters of the best type, and the employment of a pretreated varnish in the combination has already given good results by greatly increasing resistance. At present only laboratory data are available upon which to predict ultimate results, but there is a fleet of taxicabs in New York, which have now been in service for over six months, with a coat of clear varnish lacquer over colored lacquer on their bodies, and there is as yet no sign of failure. It is believed, therefore, that this material will work out in practice much better than accelerated-weather laboratory tests would indicate.

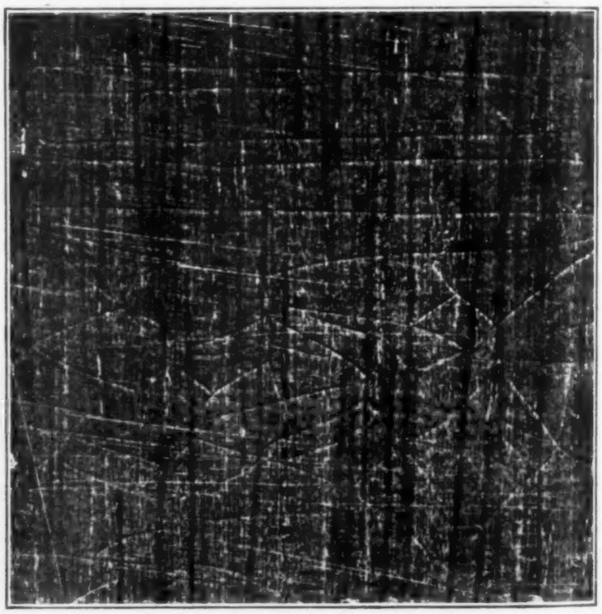

Fig. 6 Macrophotograph Typical of Old-Age Cracks

But even this promising advance for outside exposure has the disadvantage that although the endurance "on wood" out of doors is greatly improved, it is not nearly as good as that of varnish "on wood" out of doors.

This would make it necessary for the research man to develop the third-mentioned possibility, namely; a material which can be deposited in a film, will dry like a lacquer, will resist the ultra-violet rays of sunlight, and will stand up on wood out of doors at least as well as varnish does. Such a product has been developed, and fortunately it is miscible with nitrocellulose, provided it is desired to combine the two for any reason.

An idea of this material may be gained from the following: Imagine a chemical reaction for the synthetic production of amber or copal which can be arrested at a point just before hardness so that a permanent, flexible, non-sticky material re-

sults. Upon exposure to ultra-violet rays of sunlight, instead of breaking down, an exactly opposite reaction occurs. A film of this material is rendered more and more inert chemically, so that it approaches insolubility, even in solvents in which it was originally dissolved. The film gets clearer and brighter as it gets older.

Fig. 7 Panel Finished with Very Durable Spar Varnish
(Note the breaks with humidity checks at upper end. This panel was "sealed" on the back and on all sides.)

The ultimate film will be one similar to the one predicted last year by Mr. Silverstein in a very able paper—a chemical film which will be developed on the work itself.

### 5 Synthetic Lacquer Material for Work Subject to Outdoor Exposure

And now we come to the most interesting point of all to woodworkers. This synthetic material retains its plasticity permanently, so that it yields, as the most elastic varnishes do, to the severe and unequal contortions of wood surfaces.

There has never been a nitrocellulose-base lacquer in the clear or pigmented form which would stand satisfactorily on wood. Wooden panels coated with pigmented lacquer made with this synthetic material have been compared with the best automobile pigmented lacquers, at seashore points in Florida and Massachusetts, and have now had over a year's exposure. All the nitrocellulose finishes broke down in a few weeks. The panels of this base material, however, are still intact.

The greatest possibilities for such material are in the cabinet industry, for when all is said and done, strictly nitrocellulose-type lacquer does not stand up satisfactorily on cabinet work. Manufacturers have had too many instances of humidity cracks appearing on work even before it left their factory.

This promising new material would be impractical for rubbing, as formulated for outdoor service, but it is now in the stage of being proved practical for cabinet work with necessary modifications. Its promise is not so much in improvement over present types of nitrocellulose lacquers for cold-checking as it is in alleviation of the costly mischief due to humidity checking, by providing flexibility.

It is also possible with this material to build a film on work which more nearly approaches that of varnish, than do nitrocellulose lacquers of highest gum content. A comparison of Figs. 7 and 8 will indicate its wonderful possibilities. Fig. 7 shows the film result of a most durable spar varnish after six months out of doors, exposed at an angle of 45 deg., and Fig. 8 this new material exposed alongside of it.

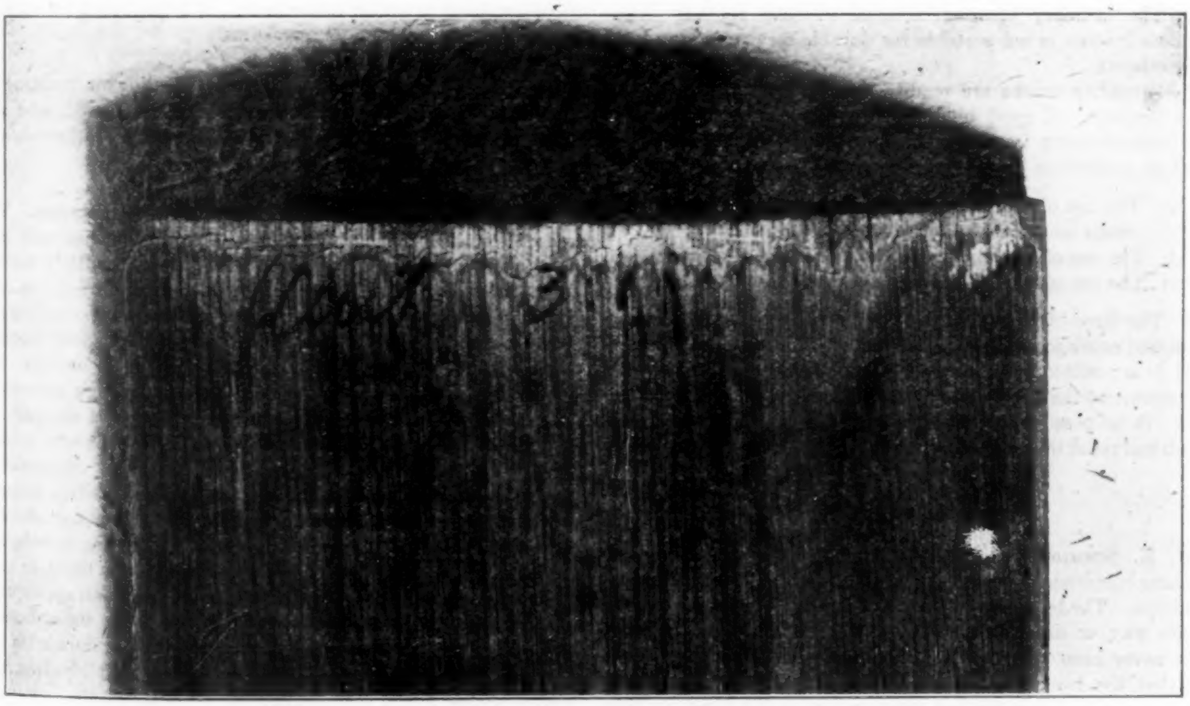

Fig. 8 Panel Finished with the Outside Lacquer, Exposed Simultaneously with Panel of Fig. 7
(Note particularly the shadow indicating the extent to which this unsealed panel warped. Note also entire absence of fractures. The ragged edge at top was caused by the slot in which panel was fitted on exposure back.)

Notice in particular that the exposure of the spar varnish is

on a close-grained hardwood—maple—and that of the new material is on a filled, open-grained wood—walnut. Also, that the spar varnish panel was sealed on the back and all sides. The new material was applied on a panel with absolutely no sealing, as is plainly indicated by its extreme warping. Its film, after this most severe test, is absolutely intact and hard as bone, despite its obvious flexibility.

The field of wood finishing with quick-drying finishes is so unscratched that these possibilities for such radical developments exist. With the problems and possible methods of solution so clearly outlined to the research man, it is not surprising that such an advance should have taken place in this relatively short period. Its further success, of course, is directly dependent upon cooperation afforded by the consumer, particularly with regard to suggesting practical refinement to the developed production.

### Conclusions

1 Varnish- and lacquer-film failures on wood are identical in so far as fractures are concerned. The same physical causes produce the same effect in each. Each type is easily and definitely recognized.

2 Varnish-film fractures may return to their original state, as far as the eye can see. Lacquer-film fractures do not.

3 A study of cracks shows them to be detectable under the microscope in approximately three-quarters of the time before they become macroscopic.

4 There is a decided basic similarity in the compounding of varnish and lacquer.

5 Varnish dries to a plastic or yielding film. Lacquer is a tight film. This is because a varnish film is always increasing in volume; whereas a lacquer film is decreasing.

6 The ordinary commercial type of easy rubbing nitrocellulose lacquer is not suitable for durable service on any kind of woodwork.

7 Humidity cracks are readily possible with nitrocellulose-base lacquers. If good building and easy rubbing properties are insisted upon, improvement for this condition in cabinet work is possible in three ways:

- *a* The use of a finish employing elastic lacquer for undercoats and varnish for top coats
- *b* The use of a combination "varnish-lacquer" product
- *c* The use of a lacquer with a synthetic plastic base.

8 The term "lacquer" should refer only to quick drying and hardness; never to the materials from which it is made.

9 It is possible to produce a synthetic lacquer material which is resistant to the ultra-violet rays of sunlight out of doors.

10 It is possible to produce a synthetic lacquer material which will resist the workings of wood, both in and out of doors.

## Discussion

W. K. Schmidt.[2] In the furniture industry the action of finishing materials is uppermost in the minds of every maker of furniture. The technical researches that have been going on in a public way or among manufacturers, chemists, and the like, have never been published for the simple reason that we have felt that the readers could not understand it. It is a pitiful admission at best, but the fact remains that such a paper as this can be understood by our practical foreman finishers.

Here in Grand Rapids we claim to have made the first nitrocellulose finish in Bissell's carpet-sweeper factory. We used cotton, ethyl acetate, and wood alcohol and made a finish out of nitrocellulose. It has been the dream of the practical foreman finisher to obtain something that would give him at once a clear solution. From the clear solution that was then obtained we were able to make a finish which was then known as "Kaiser Gray Finish."

During the World's Fair at St. Louis there was exhibited the most beautiful grade of maple that ever came to this country. We tried a year to duplicate it and finally succeeded in finding that this had a nitrocellulose finish. I have stated before that out of all of this activity in the field of wood finishes there will be evolved a new finish that has for the furniture industry the advantages of a varnish.

[2] Grand Rapids, Mich.

C. M. Bigelow.[3] Is the oxidation of varnish an advantage or a disadvantage in finish?

The Author. It is a disadvantage, because ultimately it must result in its losing its life. It is the natural procedure of its function, "breathing." When it can no longer "breathe," when the oil is saturated, we get complete oxidation and it ceases to live.

Sern Madsen.[4] Is this new synthetic lacquer applied with a brush or spray?

The Author. To all physical appearances it is the same as lacquer; it looks and smells like lacquer, because the same solvents are employed. It is therefore necessary to spray it unless especially designed for brush. I have baked it at 400 deg. for thirty minutes, and in that form have put it in boiling water and it will resist it for an hour and a half; that is the longest I have tried it, without forming any blister. It gets hard. It does not tend to soften under heat. It is produced by cooking under high pressure and temperatures.

O. M. Dunton.[5] What causes the bleeding or cracking of pigment lacquers, especially the vivid colors, as red, and also what causes the pigment lacquers to flake off on rather sharply rounded edges?

The Author. Those are both problems of formulation. The reason for the bleeding is probably the reds you had and that lake colors were employed; these colors are particularly soluble in lacquer solvents. The reason for its coming off a sharp edge is a matter of formulation, too much cotton and too little gum. Gum is quite essential to the anchorage of pigmented lacquer; cotton is not a very good adherent. Flaking is usually due, assuming the metal surface to be plain, to too high content of nitrocellulose. The first type of wood lacquer was not particularly satisfactory for the reason that you could get under a fresh film with a knife edge and strip it off. That was overcome by the addition of gum. The same thing applies to silver lacquer, where the sole object is to protect from tarnish when on display in stores. That contains practically no gum and has no adhesion to speak of, but when you come to put lacquer on brass, or anything to stand some resistance, you will have quite an appreciable content of gum, so it is really the gum that gives the adhesion and a high content of nitrocellulose is very apt to impair its adhesion. The only thing I know that will prevent bleeding is a coat of shellac mixed with aluminum. It will ruin the color, but it is the only method I know of that will be at all effective in stopping bad bleeding. Over bronze a considerable amount of gum can be put in for interior exposure.

[3] President, Bigelow, Kent, Willard Co., Boston. Mem. A.S.M.E.

[4] Mechanical Engineer, Curtis Cos., Inc., Clinton, Ia. Mem. A.S.M.E.

[5] American Seating Co., Grand Rapids, Mich.

# Improvements in Handling Methods in the Woodworking Industry

## Power-Driven Transfer Cars—Traveling Cranes for Serving Kilns—Monorail Carriers for Handling Packaged Lumber—Electric Lift Trucks—Elevators for Inter-Floor Material Handling—Disposal of Wood Waste—Various Applications of Conveyor Systems

By R. K. MERRILL[1] and G. H. RODERICK,[2] GRAND RAPIDS, MICH.

In the lumber industry, which comprises the felling of trees and their manufacture into boards or sheets of veneer, the handling methods vary greatly according to the character of the timber tracts. As several papers have been published by the Society touching on these methods, no attempt will be made here to cover that subject, and the authors will therefore consider handling methods only in that portion of the woodworking industry which starts with the purchase of boards from the lumber mills and sheets of veneer from the veneer mills, or what might commonly be called the wood-dimensioning and fabrication industry.

The methods of handling boards in the lumber yards of furniture and case-goods factories have been greatly improved during the past few years, resulting in a decrease in the number of handlings between the freight car and the dry kiln. The improved method is to load the dry-kiln cars at the freight-car door and provide yard trackage sufficient to take care of the stock of lumber, so that it is only necessary to move these cars on suitable tracks, transfer cars, cranes, etc., without the necessity of handling one board at a time. However, there still remain many lumber yards where the ground area is not sufficient, or the yard layout cannot be rearranged, to permit the carrying of the required stock of lumber on kiln cars. A manufacturer of high-grade furniture in Grand Rapids has solved that problem by acquiring a piece of land a short distance from his plant and providing a motor-truck semitrailer fitted with rails, which is used as a transfer car between the outlying lumber yard and the dry kiln at the plant.

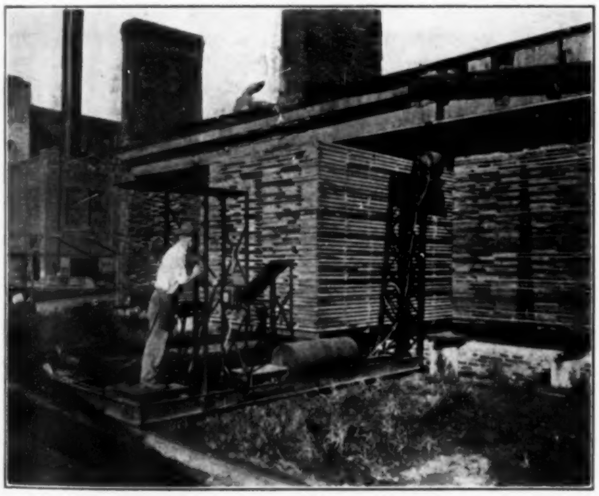

Fig. 1 Electric Transfer Car

### Power-Driven Transfer Cars

The industry has lately been experimenting with power-driven transfer cars, driven electrically or by means of gasoline motors. Each of the two types has its own field, but where possible the electric motor seems to be the more economical unit, considering power consumption and maintenance (Fig. 1). There are many locations, however, where the gasoline motor is best suited on account of the lack of electricity, but in cold climates it must be watched closely to prevent freezing in the winter time. The use of direct current is of considerable advantage in starting heavy loads as when several cars are being pushed into the dry kilns by means of the winding drum with which this type of transfer car is fitted. Where direct current is not available, the slip-ring induction motor should be used on this type of equipment. Individual motor drive on the winding drum and on the car gearing eliminates the clutch trouble experienced with single motor drive.

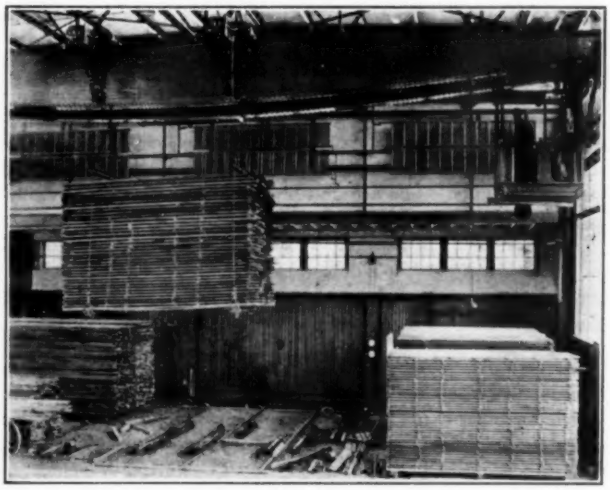

Fig. 2 Eight-Ton Traveling Crane Handling 3000-Ft. Kiln Package

### Traveling Cranes for Serving Kilns

The use of the overhead traveling crane has up until the present time been avoided by the furniture industry on account of the cost of such equipment and of the building which houses it. There are certain cases, however, where such an outlay may be necessary. A crane of this kind was recently installed by the authors in connection with the expansion of the kiln-drying facilities in a Grand Rapids plant (Fig. 2). On account of the yard layout the ten kilns previously in use could not be

[1] Chief Mechanical Engineer, American Seating Co. Mem. A.S.M.E.

[2] Assistant Engineer, American Seating Co.

Presented at the National Meeting of the A.S.M.E. Wood Industries Division, Grand Rapids, Mich., October 17 and 18, 1927.

added to, and due to the fact that they were "cross-piler" kilns and that it was desired to install "end piler" kilns, which the authors believe to be more efficient for drying certain varieties of lumber, the new and old batteries of kilns could not be served by the same transfer car. In addition to this, it was necessary to permit a railroad siding to run through the building. The building was designed to permit the installation of a crane having a capacity of 8 tons. This is a standard traveling crane such as is used in machine shops, foundries, the steel industry, etc. The use of one 8-ton trolley was first considered, but the problem involved in properly balancing the load, which is rather bulky, so as to prevent the possibility of tipping over endwise and spilling the boards out of the package, suggested the employment of two 4-ton trolleys controlled separately. This method has worked out very well, and loads are being transferred with considerable speed and perfect balance without the necessity for handling any of the boards by hand.

### Monorail Carriers for Handling Packages of Planed Lumber

A similar use is being made in the same plant of an electric monorail carrier for handling packages of planed boards to the cutters' benches (Fig. 3). These packages contain about 1500 ft. or less, depending upon the kind of lumber, and are brought into the building on a tractor-drawn trailer in lots of one or two packages at a time. They are placed in storage in the proper location by the telpher, and are taken from there and carried to the cutters' benches when wanted. This method has proved more economical of floor space than the use of industrial cars with a transfer car, as it allows the stock to be built higher, requires no aisle, and permits the moving of loads without the necessity for handling one board at a time. It is of course necessary that the building be constructed heavy enough to support the monorail track, but it so happens in this case that this track is installed on the ceiling of a very high first floor of what is intended to be a four-story building, so that it was not necessary to build extra strength into the floor in order to support the monorail. The average woodworking factory, unless provided with a high first story, would probably find this method somewhat difficult, particularly the older type of mill-construction buildings.

### Electric Lift Trucks

Engineers in general are familiar with the remarkable savings which have been made through the introduction of conveyors in automobile machine shops, thus cutting down what Mr. Ford calls the "handling in making." At this point it is well to remember that handling forms a larger proportion of the cost of woodworking operations than it does of most machine-shop operations for the reason that the cuts are made rapidly and in quick succession. Very often it will prove economical to use the ordinary type of factory truck so that machine operators can shift a fresh load of stock to the machines without waiting for the regular truckers, who are hired for this purpose only. However, lift trucks, both hand-operated and electric-driven, have been used by the authors with some considerable economy. The electric lift truck (Fig. 4) usually requires a larger and higher platform than the ordinary hand lift truck, but this difficulty was met by building a platform on top of a hand-lift-truck base which would handle the higher platform needed for the electric lift truck, thus providing a bridge between the two types of equipment. The electric lift truck is used generally for the long-haul and between-floor movement of material. Short pieces of cut and ripped stock are handled best on the platform type of equipment. Maintenance of floor surfaces and of trucking equipment is less where this type of truck is employed than with the old-style factory truck commonly used by the woodworking industry.

### Elevators for Inter-Floor Material Handling

In considering material-handling facilities, one should not forget the elevator for carrying material between floors. Many of the old woodworking factories are provided with the old-style belt-driven elevator which starts the load by shifting the belt. In some cases these elevators were driven from the main lineshaft, which latter piece of equipment has practically disappeared from the modern plant on account of the introduction of the electric drive. It has been the authors' experience that the most modern elevator equipment possible within the limits of the money available should be provided in woodworking plants, and that the cars of these elevators should be large enough to give plenty of room for all types of loads. It might be necessary to install cutting-up and dimensioning operations on an upper floor for some particular class of goods, and the large elevator car lends itself very well to this layout. Within the past nine years the authors have seen elevator speeds increased from 40 ft. per min. in the old plant to 150 ft. per min. in the plant completed during the present year. Changes in elevator equipment were made a few years ago giving speeds of 80 and 100 ft. per min., but even the two 5-ton elevators at 150 ft. per min. last installed do not seem to run fast enough, although they have been in operation less than a year. These two units were designed for use with the latest switching equipment and are push-button-controlled with variable voltage control. Operators are eliminated and the trucks are operated by the electric-truck operators above referred to. In the last case, crating lumber is brought in from the lumber yard by gasoline or electric tractors, placed on the elevator and carried to the fourth floor, where it is cut up by the swing saw at the crating operation. A small elevator car would have prevented such an arrangement.

### Grouping of Continuous-Feed Machines into a Conveyor System

A considerable saving in handling is possible where continuous-feed machines can be grouped together so that their chains form a part of a conveyor system. The authors have one case in mind where two double end tenoners are placed end to end with a boring machine intervening and a shaper at the outfeed end of the last tenoner. The material is fed into the first tenoner, and the man who does the handling between the two tenoners also does the boring operation as he handles each piece. The shaper men take their work from the last tenoner, and when they have finished the shaping operations, it is ready for sanding. It was necessary to synchronize the machine feeds so that work would not pile up between them. Such an arrangement means a saving in floor space and production time. The rearrangement of this battery of machines from its former location resulted in the saving of about $3500 a year due to the elimination of machine feeders alone, without taking into account the item of floor space.

The introduction of the continuous clamp carrier has resulted in a saving, and while this is considered as a machine it is actually a conveyor. Most up-to-date woodworking plants are equipped with this device. There are several good ones on the market, both hand- and power-operated, but for continuous production the authors prefer the power-operated machine in the large units and the hand-operated one for small work.

### Disposal of Wood Waste

Any discussion of the handling involved in woodworking operations also brings up the question of the best method of disposing of the wood waste caused by these operations. That this is a large factor in the power demand in a woodworking factory is

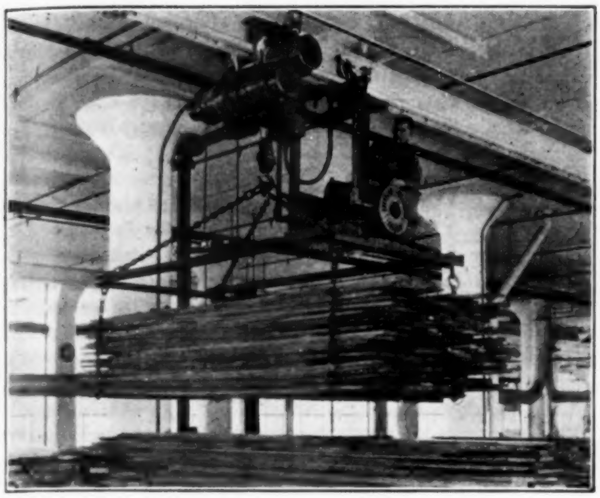

Fig. 3 Three-Ton Monorail Carrier Handling Packages of Planed Lumber to Storage and to Cutting Benches


Fig. 4 Two-Ton Electric Lift Truck Handling Wood Scooped Seats in Process of Manufacture

Fig. 5 Layout of Exhauster Fans and Dust Collectors on Roof of Woodworking Factory

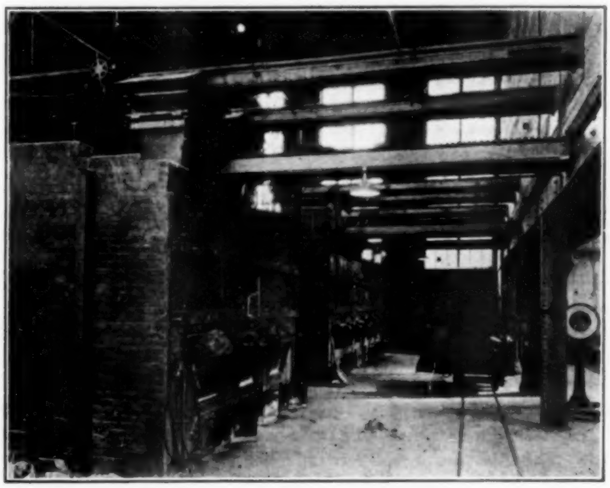

Fig. 6 Boiler Room with Furnaces Equipped with Screw Feed for Shavings and Hogged Fuel

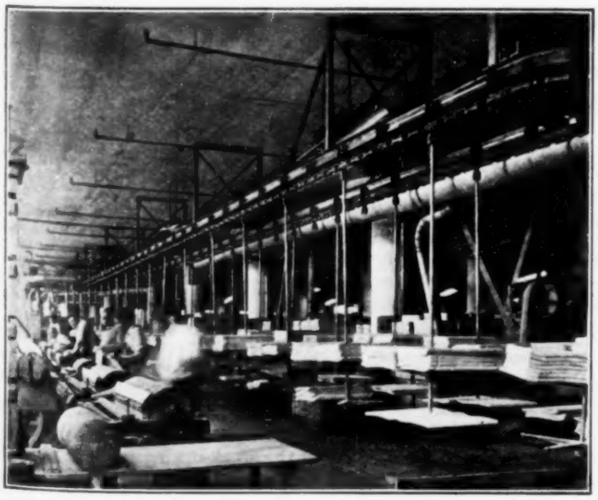

Fig. 7 Conveyor for Handling Stock Between Several Sanding and Inspection Operations

Fig. 8 Conveyor for Drying Stained Pieces

proved by the following figures. In two factories producing about the same type of goods with which the authors are familiar, the power required to drive blowers producing the necessary draft for removal of shavings and dust was 25 per cent of the total power required to operate the factory, including conveyors, elevators, hot-blast heaters, etc. This figure was exceeded in another factory, where it was about 50 per cent, due to the nature of the work performed, the cuts being very light and the proportion of air moved to weight of shavings and dust being greater. In some woodworking operations, such as flooring mills, the proportion of power required for handling shavings would be less, due to the concentration of the machining operations in a few high-speed machines. In any case it is well worth the engineer's time to devote considerable thought to the layout of these blower systems. A large factor of safety is necessary for future expansion as well as continuous performance, and also because the character of the shavings has a bearing on the amount of friction introduced into the duct system. For example, a blowpipe system, as it is called, might function perfectly on light sander dust, but would give trouble when machines producing coarse chips were connected to it. On the other hand, an overpowered system is wasteful, as it is usually necessary to operate it as a unit whether or not all of the machines connected to it are producing waste material.

In the plant with which the authors are connected, it is the custom to offer for sale all of the end cuttings from the boards. It is cheaper to do this and buy coal to replace it as fuel, since this type of material is rather hard to fire by hand and requires too much power to reduce it to small pieces. The last-mentioned method, namely, the use of a shredder for reduction of rippings, small end cuttings produced by the machining operations, and plywood scraps to a size which can be fed into the blower system, has proved economical of handling and allows this type of material to be fed into the boiler furnaces without opening the furnace doors. The furnaces are fed by means of screw conveyors feeding out of the bottom of a concrete bin where the shavings and crushed wood have been deposited. This screw feed has proved to be much more satisfactory than the older method of feeding directly out of the dust collector on top of the boiler house, for the reason that it allows the feeding to be governed automatically by controlling the speed of the engine driving the screws. A standard stoker control is used for this purpose. Excess air, which is often present when the shavings volume falls off suddenly in the factory and the fireman does not get a chance to regulate his blowpipe gates properly, is prevented from entering the boiler furnace with its damaging effect on the setting and tubes. The wood shredder is served by a standard fabric-belt conveyor similar to that used on coal, stone, etc., which brings small cuttings from the miter saws and similar machines to the shredder location. It has been found necessary to provide an operator on the shredder on account of the disastrous effects of large nuts, wrenches, and other foreign material which often find their way into the machine. Some of the material is also dumped down to the shredder location from the upper floors through a metal chute. Periodical inspection of the shredder—every six weeks—is necessary in order to dress up the hammers and grid, and keep everything in proper working order. At first it was the custom to feed used crating material, which had nails in it, through this shredder, but it was decided, after two or three experiences with fire, to burn such material by hand-firing methods where the nails could do no harm.

### Handling of Stock Between Successive Sanding Operations by Overhead-Trolley Conveyor

Where several operations are performed in succession, as in the sanding of wood parts, the overhead-trolley conveyor driven by a chain has been found satisfactory and to effect a considerable saving in floor space and handling (Fig. 7). All the machines in the layout are grouped around the chain conveyor, which has suspended trays hanging from the overhead chain. In this way quite a large group of men can be served with work without any delay and without the use of any hand trucks. After the stock has been routed and shaped, the inspector places it on the upper tray of the conveyor. The conveyor moves past the drum sanders, who remove the stock, perform their respective operations, and return the stock to the conveyor, this time on the lower tray. The conveyor then passes the spindle-sanding operation, where the stock is removed, spindle sanded, and placed on trucks to be taken to the staining operation. This conveyor dispenses with all trucking operations between routing and spindle sanding, keeps stock moving, thereby cutting down stock in process, and eliminates congestion.

The production of plywood parts involving the use of a hydraulic press, together with cauls held under pressure by clamps, has required the use of some method of storage and handling these cauls. In the furniture trade the cauls are quite large and weigh close to one ton each. It is a common practice to handle these on factory trucks. Our experience covers a period of about 15 years, during which this operation has been improved, starting out with old-style strap clamps held by steel wedges driven in by hammering, and handled on common two-wheeled warehouse trucks. The first improvement made was the substitution of a new press and clamps of the I-beam and turnbuckle-retainer type. The press was arranged with a roller unloader so that the cauls could be run out on the rollers and picked up off these rollers by means of a lift truck. The cauls were then allowed to stand during the drying period on lift-truck platforms. This change, which was made some years ago, resulted in an immediate reduction of 40 per cent in the number of men required to turn out the product, and later in an increase in the production by the reduced crew as soon as they became accustomed to the new order of things. The next step to reduce handling was the use of a roller conveyor in connection with a drag chain for removing these cauls from the press, during the drying period, and returning them to the press for reloading. This change resulted in a 25 per cent decrease in cost as compared with that obtained by the first improved method. Another arrangement, which has not been in production long enough to determine the saving accurately, is now being substituted whereby the cauls will be handled on a chain-driven overhead-trolley conveyor which is started by one of the operators and stopped automatically so that the cauls are in the right position for handling on and off the suspension hooks attached to the trolleys. This raising and lowering of the cauls is done by means of compressed-air hoist underneath the roller tables leading to and from the hydraulic press.

### Conveyors for Handling Stained Wood Parts

The finishing of wood parts offers a field for the use of conveyors. The old method of staining small parts was to dip the pieces in a tank of water stain and stack them up to dry on a drainboard. For some time past the authors have been experimenting with stain driers consisting of a conveyor chain with specially fitted links provided to hold the stock so that no marking at the contact points would be observed. The first one of these driers was a rather complicated-looking affair, having a hot blast of air traveling across the top of the conveyor table. This was done in order to avoid the possibility of having trouble with the drip of the stain, which drips off the stock during the first few feet of travel of the conveyor. However, when more room was available it was found that a rather long conveyor with only slight amount of heat worked out very much better. The pieces

are dipped in the tank and set on the conveyor (Fig. 8), which carries them over steam radiation and then underneath a blast of warm air. They are finally inspected at the end of this conveyor and the good pieces placed on a roller conveyor which runs parallel to the stain-drier conveyor but in an opposite direction. The inspected and passed pieces roll down by gravity to the operators, who apply the first coat of shellac or sealer. The introduction of this scheme resulted in an increased production by the first coaters and also allowed us to effect a reduction in the labor cost of staining of 40 per cent. A second conveyor was installed for some smaller pieces which has no heat applied to it, but the extra length of travel is sufficient so that the parts are dry enough to handle when taken from the end of the conveyor. The use of this conveyor resulted in a saving of 50 per cent in the cost of doing the work, as well as in freeing a considerable amount of floor space formerly needed for the drying operation. The adoption of lacquer finishes, which must be applied by spray guns in booths, has finally led to the intro-

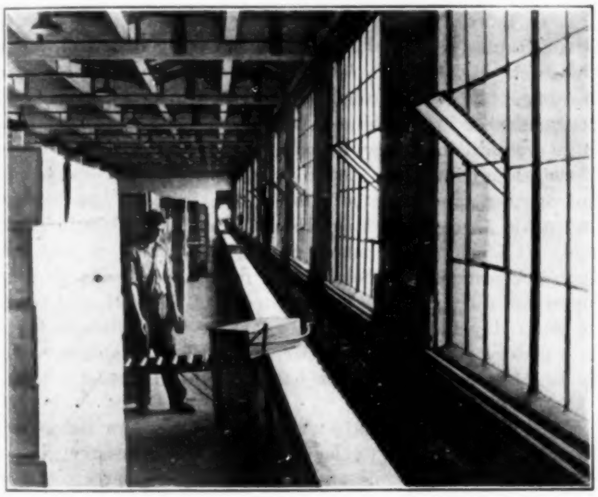

Fig. 9 View of Conveyor Feeding Cartons off to Storage Pile

duction of a conveyor for handling pieces to and from the operators at the booth. Several experimental conveyors for this work have been installed by the authors and the results of the experiments have shown that it is necessary to keep the conveyor parts covered from the action of the lacquer spray, as the lacquer tends to build up a coating on these parts and this must be removed by rather careful scraping on account of the fire hazard. The most satisfactory type at present developed by them seems to be the overhead-trolley type, driven by a chain with carriers suspended so that only the carriers pass through the booths. An unlooked-for development in connection with this conveyor was the application of a heavier coat, due to the fact that the operator could stand directly over the work. The pieces being coated in this case average about 18 in. wide × 24 in. long, and are supported on rubber-tipped wooden pegs attached to the suspended carrier. The previous experiments were conducted on a straight-line conveyor, while the last-mentioned conveyor is an endless overhead conveyor. This made it possible to place the spray booths on opposite sides of the hollow square enclosed by the conveyor trolley rail, which resulted in a 20 per cent decrease in the labor cost of handling the pieces and applying the coats below that shown by the first experimental installation.

### Miscellaneous Conveyor Applications

The use of conveyors for the assembly of automobiles, refrigerators, kitchen cabinets, etc. is well known. The authors have had considerable success with the use of an ordinary wood-slat conveyor, which forms in effect a moving bench top on which to assemble wood and steel parts. The parts are fed on to the conveyor at the proper point and the finished product is inspected and placed in the packing carton at the end of the conveyor. The carton is sewed shut and is then ready for storage and ship-

Fig. 10 Discharge End of Conveyor Feeding Cartons into Freight Car

ment. This conveyor resulted in an increase in production and a consequent decrease in cost amounting to 10 per cent. It was formerly the custom to have the trimming department do the assembly work and then handle the completed assemblies to the packing department, which put the assemblies into the shipping cartons. By rearranging this operation in connection with the conveyor, the trucking between these two departments was eliminated and considerable floor space devoted to the handling of the bulky trucks was released for other uses.

The final shipment of the product in cartons is facilitated by a belt conveyor which runs along one side of the warehouse building. This conveyor is about 380 ft. long. It also serves to carry a portion of the product from the packing operation to the storage pile (Fig. 9), and makes it possible to place the wood parts in cartons and have them go direct from the closing operation to the freight car (Fig. 10).

In general, the authors' observation in connection with the installation of conveyors has been that departmental foremen are inclined to keep operations intact, but as soon as a conveyor is installed and operations which occur in sequence although in different parts of the plant are moved together on the conveyor, this antagonism disappears. Recently, the authors built a new plant the entire second floor of which was laid out to take the operations in sequence, so that the finishing is now being done in the same room with the gluing, planing, machining, and sanding. After finishing, the assembly operations were added on the wood-slat conveyor mentioned above, so that a large portion of the material which enters this room at one end ready for gluing, leaves it packed in the shipping carton ready for the customer.

## Discussion

P. H. Bilhuber.[3] The lumber-handling system in the cutting room of the American Seating Company which we saw this morn-

[3] Asst. Factory Manager, Steinway & Sons, Long Island City, N. Y. Assoc. A.S.M.E.

ing looked to me to be rather expensive. Has the cost of this investment been figured against the labor saving effected?

R. K. Merrill. In answer to Mr. Bilhuber's question, we have been cutting 30,000 to 32,000 ft. of lumber a day using this method. The other method of handling, using kiln bunks, transfer cars, etc., would have required more floor space than we had available in that location, and we decided to adopt the present method after figuring up the cost of the installation, which I believe was about $4500. The monorail track is close to 500 ft. long, and the hoist has a capacity of 3 tons.

Charles Kindel, Jr.[4] Can Mr. Merrill tell something of the method used by his company in reclaiming lacquer? I understand that as much as 10 per cent is being recovered.

R. K. Merrill. I did not mention the subject of reclaiming lacquer because this is a conveyor paper, but since using the conveyor, we have started to reclaim a portion of the lacquer. Lacquer is quite expensive, and if it can be reclaimed there is just that much more for the next day's use. We find it is not damaged. It is necessary, of course, to add thinner. I believe we are reclaiming on this particular conveyor mentioned a quantity of lacquer amounting to about ten per cent of the day's use. This is reclaimed by having detachable plates in the bottom and at the back of the booth, which can be removed and immersed in the thinner tanks. Every conveyor we build seems to us to be better than the one before, and it often happens that it is quite different, because we get ideas from one conveyor which we incorporate in the next. We have in mind another spray booth and lacquer conveyor system to be installed, operated entirely differently from the one described, with the reclaiming feature incorporated in the booth.

Arthur Koehler.[5] One interesting feature is putting the pieces through the drier after they have been dipped in the stain. We think that this operation requires considerable attention. If the water stain or the water used in sponging to raise the grain remains on the wood for any length of time and gets a chance to soak in, and it does not have to soak very far, it is apt to cause trouble. We believe some of the fine checks we get in finishes are due to that very thing. This may require a little explanation. If the surface of a dry board becomes wet, it tends to swell. The wet region does not extend very far inward and the whole board will not swell because the inside does not get wet. Therefore the surface cells, in trying to expand, become permanently crushed, so that when the surface dries out again, as it will, the cells will shrink away from each other and produce fine checks. Just how serious that is in wood finishing I do not know. The water should be dried off as rapidly as possible after it is applied, because it is only necessary to wet the surface.

R. K. Merrill. We agree with Mr. Koehler's contention, and of course the application of water immediately after the planing operation has always been a bugbear with us. We have in mind a conveyor to handle these peices, and in this new location the conveyor can be attached to the ceiling and carry for quite a distance without interfering with anything.

Burritt A. Parks.[6] Our line is more particularly connected with the power plant, and consequently I am more interested in conveyors supplying refuse to boiler furnaces. In one plant which we installed recently, we used a little different scheme for automatically conveying refuse to the boiler furnaces. We use a Dutch-oven furnace similar to one at the American Seating Company. We convey the shavings and sawdust into a shavings bin similar to the old type of shavings bin, and out of the bottom of that bin we take the shavings into a screw conveyor, which empties or discharges into a fan. The fan discharges through the roof of the boiler house into another separator and is carried thence into the furnaces. Automatic control is provided. Taking the shavings and sawdust out of the bottom of the main shavings bin allows us to reduce very materially the excess air discharged into the furnaces. As to whether that particular scheme is more efficient or not than direct feed into the furnaces, I cannot say without making a comparative test. I dare say there would not be much difference between the two. Both of the schemes practically accomplish the same object, and that is to feed the shavings and sawdust to the furnaces in accordance with the demand for steam, and also to get rid of excess air.

T. D. Perry.[7] I only wish it were possible to bring back to Grand Rapids, as we did some years ago, my good friend, Frank Gilbreth. Mr. Gilbreth was here, I should judge, nearly ten years ago, and went through some of the furniture factories. If you remember Frank Gilbreth at all, you will know that he was quite dramatic in the way he expressed himself. He went to one of the leading factories—not, by the way, Mr. Merrill's factory, but another—and after he came out he took his handkerchief and made an excellent stage imitation of profuse weeping and said, "If I could only have for mine the amount of time and energy consumed in these plants in Grand Rapids, pushing boards in and pulling them out." If Mr. Gilbreth could only be here today and see the changes that have been brought about in a factory administered as Mr. Merrill has administered his, he would have no cause for the use of that handkerchief.

Sern Madsen.[8] In 1916 when we built our new factory, we found that in addition to the shavings it was necessary to burn 3700 tons of coal in one year. We then designed a conveyor system to remove shavings from underneath the bins. It serves 4 boilers and has one motor with automatic control. The first year we saved 2700 tons of coal by cutting out excess air and getting fuel into the boilers when we needed it. I have been interested since that time in watching a number of other plants put in some sort of system for boilers controlled by steam pressure, and greatly amused in seeing how some of these plants are put in. I know one in particular, where two boilers are fired. There are two stoker engines, two extra bins, and two conveyors for each boiler, in addition to a fan to blow the shavings, and three or four electric motors. We have four boilers and do it all with one motor and one conveyor. They get results all right, but I have always wondered why they use so much equipment when there is a shorter method of doing it. There is always a possibility of simplification in installing any conveyor system.

There is one method of conveying which has not been mentioned. I refer to overhead cranes for handling rough lumber in long lengths. There is also another tool, developed in the last few years, a type of carrier that runs considerably like a hen with a brood of chickens, and one man with one of these affairs will handle as much as 80,000 ft. of lumber a day, and do it easily. This truck will go anywhere that there is a cement or plank runway. I am not so sure how it would work out in a furniture factory, but it does work in a sash-and-door factory.

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[5] In charge, Office of Wood Technology, Forest Products Laboratory, Madison, Wis.

[6] Cons. Engr., Byron E. Parks & Son, Grand Rapids, Mich. Mem. A.S.M.E.

[7] Director, Woodworking Division, Bigelow, Kent, Willard & Co., Inc., Boston, Mass. Mem. A.S.M.E.

[8] Mechanical Engineer, Curtis Cos., Inc., Clinton, Iowa. Mem. A.S.M.E.

# Static Loads upon Bus Bodies

## A Report of Tests Made to Determine the Static Loads Due to Interaction of Body and Chassis upon Which It Is Mounted, and a Description of the Methods Employed

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THE STATIC loads upon bus bodies can obviously be divided into two groups: those due directly to the weight of the passengers and those due to the interaction of the body and the chassis upon which it is mounted. The latter loads occur at the points of fastening of the body to the chassis, and are usually indeterminate because of the multiplicity of these points. It is the purpose of this paper to point out the importance of these loads and to suggest a physical or experimental method by which they may be determined.

The usual bus-body design provides posts between the windows, spaced at intervals of 30 to 40 in.; longitudinal members fastened to the tops and bottoms of the posts and extending the full length of the bus body; and other longitudinal members fastened to the posts just above and below the windows and extending the full length of the bus body upon the left side and between the front and rear door upon the right. The rectangular spaces formed by this framework above and below the windows are paneled with some suitable material. This paneling is an effective cross-bracing and gives the body great stiffness.

The usual chassis-frame design provides two longitudinal members (usually of channel cross-section) fastened together by several transverse members. The longitudinal members are usually from 4 to 6 ft. apart and are overhung by the bus body. The bus body is usually supported at the foot of each post by short transverse cantilever beams or "outriggers" which are securely fastened to the longitudinal members of the chassis frame.

From an examination of the design one would suppose that the outriggers were intended to carry that part of the passenger load placed above them. This intention is realized only if the stiffness of the bus body is small compared to that of the chassis frame. A design fulfilling this condition does not seem practical. Either the chassis frame would have to be extremely rigid or the bus body would have to be very flexible indeed.

Josephs[3] has lately pointed out several objections to both of these conditions. He also mentions that general practice in bus-body design is quite contrary to them, the stiffness of the average body being about six times the stiffness of the chassis frame upon which it is mounted. Evidently the above intention is not realized in the average bus. The passenger load distributes itself among the outriggers in a way determined by the elastic properties of the structure. Usually the chassis frame acts as a beam supported at the wheels. The bus body rests upon this beam and extends over the rear support but does not reach the front support. If all outriggers are removed except those over the rear wheels and those at the front edge of the body, the problem becomes a very simple one. The chassis bends concave upward because of the load placed upon it by the front edge of the bus body. The bus body also bends slightly concave upward due to the passenger load within it; but the body has so much more stiffness than the chassis that its curvature is much less than that of the frame. Thus the vertical distance between the chassis frame and the body near the center of the body is greater when the bus is loaded than when it is empty. If the outriggers which we have assumed removed were left in place they would tend to hold the chassis frame at a constant distance from the body throughout its length, and therefore some of the fastenings would necessarily be in tension. The chassis frame would be pulling downward upon the body at these points.

Two methods of overcoming this difficulty suggest themselves. The bus may be designed like the old two-wheel cart. The engine and front wheels take the place of the horse, and the rear wheels carry the entire passenger load. The bus body and the chassis frame both bend convex upward due to the passenger load. If the body is six times as rigid as the frame the outriggers near the fastenings of the rear spring carry about six-sevenths of the passenger load, the rest being distributed among the remaining outriggers. The second method is more unusual and has only lately been adopted by a few builders. The bus body is extended the full length of the chassis and the engine is mounted somewhere under the body instead of in front of it. In this case (assuming again that the body has six times the stiffness of the chassis) six-sevenths of the passenger load is carried by those outriggers near the spring fastenings of both front and rear springs; one-seventh of the load being divided among the remaining outriggers.

Even if the above methods are employed one cannot be sure that the loads upon all the outriggers are downward unless the ratio of the stiffness of the body to that of the chassis frame is the same at all transverse sections of the bus. This condition is difficult to meet because the door openings, etc. cause a variation in the stiffness of the body, and the change in the cross-section of the longitudinal members causes a variation in the stiffness of the chassis. It seems best to design with this condition in mind, build a sample body, and determine from it the actual reactions between the body and the chassis. If some of the outriggers are found to be pulling downward upon the body they can be removed and the bus retested to determine the result. If several of the outriggers are found to be pulling downward upon the body and only a few supporting it, the removal of these few may reverse the load upon the remaining outriggers and distribute it more equally.

The method of test proposed by the authors consists of two steps: first, a test upon the sample bus, and second, a physical analysis of the data obtained. In the test upon the bus, attention is focused upon the longitudinal members of the chassis because their strength properties are usually known. The test consists of noting the changes in the deflection curves of these members due to the application of the passenger load. The points of application of direct loads to these members, such as spring fastenings, outriggers, etc., are noted and recorded. At least one deflection reading is taken for each load close to but not necessarily at the point of application of the load. The greater the number of points at which deflection readings are taken and the more uniformly they are distributed along the longitudinal member, the more nearly accurate will be the determination of the loads.

A physical analysis of these deflection data may be obtained by loading a model beam in such a way that its deflections are proportional to the deflection readings taken from the longi-

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[3] L. C. Josephs, Jr., Engineer International Motor Co., "The Design of Motor-Bus Bodies," *Mechanical Engineering,* Mid-May Number, 1927, vol. 49, no. 5a, p. 510.

Presented at the National Meeting of the A.S.M.E. Wood Industries Division, Grand Rapids, Mich., October 17 and 18, 1927.

tudinal members of the chassis. This analysis is first applied to the data taken upon one of the longitudinal members and then to the data taken upon the other. The model beam should be made so that the ratio of its stiffness to the stiffness of the longitudinal members of the chassis is the same for corresponding sections. Also the loads should be applied to the model beam at points corresponding to the points of application of loads upon the longitudinal members. The loads obtained in this manner are proportional to the loads upon the longitudinal members of the chassis frame due to the application of the passenger load. Therefore if the total passenger load used in the bus test is known, the loads upon the chassis can be determined from the loads upon the model beam by a simple proportion.

Let us now consider some data taken in a test upon a bus of the two-wheel-cart design. The test was made at the factory of the Lang Body Company upon a bus of their manufacture. The privilege of making this test and the assistance rendered by the personnel of the company are greatly appreciated by the authors.

The bus was run over a pit in the factory, and a heavy wooden beam extending its full length hung under it. This beam was supported by wires fastened to the chassis at the front of the front springs and at the rear of the rear springs. Transverse beams were fastened to it. These beams supported arms at their ends which held Ames dials against the under surface the longitudinal members of the chassis. Sand bags were used for the passenger load. The deflection data obtained are shown in Table 1.

TABLE 1 DEFLECTIONS OF THE LONGITUDINAL MEMBERS OF THE CHASSIS FRAME

DEFLECTIONS OF LEFT SIDE, IN.

| Distance from front, in. | 0 | 55 | 92 | 130.5 | 180 | 220.75 | 286.5 | 306.5 |
|---|---|---|---|---|---|---|---|---|
| Load in lb. | | | | | | | | |
| 1920 | 0 | 0.028 | 0.034 | 0.037 | 0.030 | 0.022 | 0 | 0.020 |
| 3600 | 0 | 0.054 | 0.065 | 0.074 | 0.062 | 0.053 | 0 | 0.044 |
| 5280 | 0 | 0.074 | 0.085 | 0.095 | 0.079 | 0.071 | 0 | 0.057 |

DEFLECTIONS OF RIGHT SIDE, IN.

| Distance from front, in. | 0 | 53 | 94 | 131 | 179 | 222 | 286.5 | 307.5 |
|---|---|---|---|---|---|---|---|---|
| Load in lb. | | | | | | | | |
| 1920 | 0 | 0.002 | 0.006 | 0.007 | 0.001 | −0.009 | 0 | 0.018 |
| 3600 | 0 | 0.005 | 0.012 | 0.014 | 0.003 | −0.013 | 0 | 0.032 |
| 5280 | 0 | 0.008 | 0.017 | 0.020 | 0.003 | −0.019 | 0 | 0.038 |

The model beam used by the authors was made of poplar veneer $^1/_4$ in. thick and one-fourth the length of the longitudinal members of the bus chassis. Its width varied in such a manner that its stiffness at any section was proportional to the stiffness of the longitudinal chassis members at a corresponding section. The loads were applied to this model beam by means of twine and rubber bands. Fig. 1 is a photograph of the apparatus used. A sheet of drawing paper upon which the deflections of the longitudinal members of the chassis frame were plotted was fastened to a blackboard. The model beam was held in front of this paper by twine and rubber bands as shown. The tension upon the rubber bands was varied until the model beam was made to conform to the plotted deflection curve of one of the longitudinal members. The length of each of the rubber bands was then recorded and the test repeated for the other longitudinal member. Subsequently the forces applied by the rubber bands were determined by loading each band separately with gram weights so that the recorded length was again obtained. These weights corrected for the deadweight of the model beam are given in Table 2. The loads upon the chassis frame due to the passenger load can be determined from these weights by the following simple proportion:

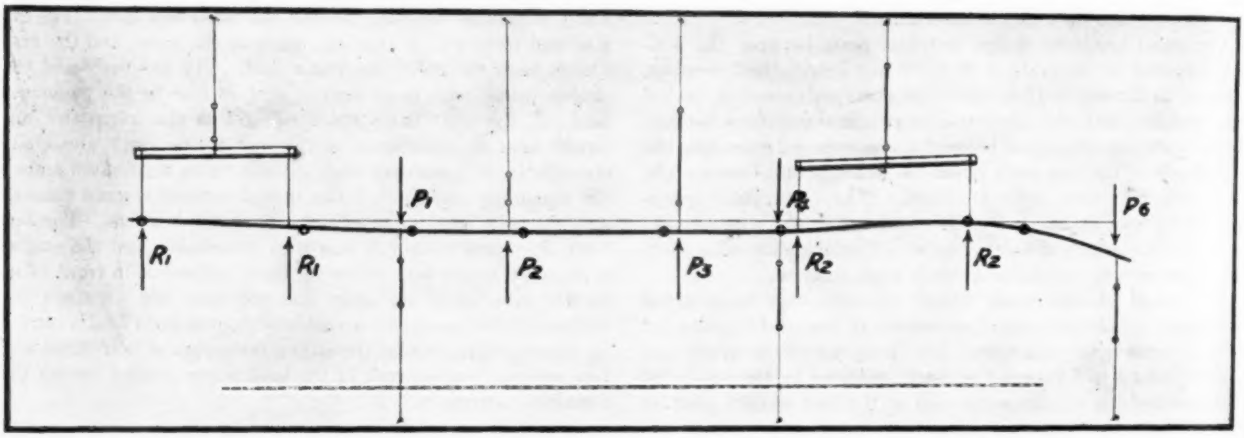


FIG. 1 MODEL BEAM SUPPORTED AGAINST DRAWING PAPER ON WHICH DEFLECTION WERE PLOTTED

$$\frac{\text{Load at specific point on one of the longitudinal chassis members}}{\text{Half the passenger load}} = \frac{\text{Corresponding load upon the model beam}}{\text{Sum of those loads upon the model beam which correspond to the loads applied by the bus springs to the longitudinal chassis member}}$$

The right-hand member of this proportionality is expressed in percentage and shown in Table 2. For convenience in computing the loads upon the chassis, hălves of the values of the left-hand members of the proportionality are expressed in percentage and given in Table 3 with a tabulation of the actual loads upon the chassis due to a passenger load of 5280 lb.

These loads were plotted graphically together with their shear and bending-moment diagrams and also the deflection curves obtained in the test of the bus. It was noted that the bus is a good example of the two-wheel-cart type. The front springs support very little of the passenger load, the rear springs taking nearly all of it. Yet it will be noted that the bus body is pulling upward strongly upon one of the outriggers located near its center on the left-hand side and bearing down heavily upon the next outrigger to the rear. Also the outrigger just to the rear of the rear spring is not carrying any of the load. If the first-mentioned outrigger were removed the second one would probably not bear down so heavily, and the third might help support the passenger load. Another test with the outrigger removed would determine this. The shear and moment diagrams are

interesting in connection with the chassis design, but give little information concerning the body.

The authors realize that this is not a complete paper but only a beginning of a practical analysis of the stresses encountered in bus bodies. They hope that it will give a slight impetus to the best engineering thought upon this subject.

An examination of these data shows that a hysteresis effect exists, i.e., the load-deflection curve taken with increasing loads is not identical with the curve taken with decreasing loads. Correction was made for this effect by averaging the deflections at each point taken at the same load. The results of this correction are in Table 1.

The data in Table 1 give three elastic curves of the chassis frame for each side of the bus. The deflections at the 1920-lb. load and the 5280-lb. load were reduced to equivalent deflections at 3600 lb. by multiplying them by the ratio of the loads. The three sets of deflection data were then averaged and the probable error of the mean computed. These data are given in Table 6.

TABLE 2 FORCES UPON THE MODEL BEAM

| | $R_1$ | $R_1$ | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $R_2$ | $R_2$ | $P_5$ | $P_6$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Distance from front in $^1/_4$ in. | 0 | 50 | 88 | 125 | 185 | 219.5 | 226.5 | 286.5 | 289.5 | 338.5 |
| Forces when model beam conforms with deflection curve of left side, in grams | −45 | −45 | 189 | − 35 | −575 | 1984 | −979 | − 979 | 0 | 451 |
| Forces when model beam conforms with deflection curve of right side, in grams | − 4 | − 4 | −146 | 200 | 91 | 1302 | −1272 | −1272 | 717 | 385 |
| Forces upon left side expressed in per cent of reactions on left side | − 2.2 | − 2.2 | 9.6 | − 1.4 | − 28.1 | 97.3 | − 47.8 | − 47.8 | 0 | 22.6 |
| Forces upon right side expressed in per cent of reactions on right side. | − 0.4 | − 0.4 | − 7.3 | 8.1 | 3.6 | 51.8 | − 49.6 | − 49.6 | 28.5 | 15.3 |

TABLE 3 FORCES UPON THE CHASSIS FRAME DUE TO THE PASSENGER LOAD

| | $R_1$ | $K_1$ | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $R_2$ | $R_2$ | $P_5$ | $P_6$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Distance from front of bus to point at which force is applied—in in. | 0 | 50 | 88 | 125 | 185 | 219.5 | 226.5 | 286.5 | 289.5 | 338.5 |
| Forces upon left side expressed in per cent of passenger load | − 1.1 | − 1.1 | 4.8 | − 0.7 | − 14.1 | 48.7 | − 23.9 | − 23.9 | 0 | 11.3 |
| Forces upon right side expressed in per cent of passenger load | − 0.2 | − 0.2 | − 3.7 | 4.1 | 1.8 | 25.9 | − 24.8 | − 24.8 | 14.3 | 7.7 |
| Forces upon left side at full passenger load of 5280 lb. | −58 | −58 | 254 | − 37 | −745 | 2570 | −1262 | −1262 | 0 | 597 |
| Forces upon right side of full passenger load of 5280 lb. | −11 | −11 | −195 | 217 | 95 | 1361 | −1310 | −1310 | 755 | 407 |

## Appendix

THE purpose of this appendix is to record the experimental data and to show the method of analysis and computations in detail.

TABLE 4 DEFLECTION DATA OBTAINED FROM BUS TESTED

(Deflections shown in thousandths of an inch, positive downward.)

Left side facing forward

| Distance from front, in. | | 55 | 92 | 130.5 | 180 | 220.75 | 286.5 | 306.5 |
|---|---|---|---|---|---|---|---|---|
| Passenger load, lb. | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1920 | 0 | 19 | 30 | 32 | 25 | 19 | 0 | 19 |
| 3600 | 0 | 49 | 66 | 76 | 64 | 52 | 0 | 50 |
| 5280 | 0 | 74 | 85 | 95 | 78 | 69 | 0 | 57 |
| 3600 | 0 | 58 | 64 | 71 | 57 | ... | 0 | 38 |
| 1920 | 0 | 37 | 39 | 42 | 34 | 21 | 0 | 20 |
| 0 | 0 | −1 | 0 | −1 | −3 | −4 | 0 | 0 |

Right side facing forward

| Distance from front, in. | 0 | 53 | 94 | 131 | 179 | 222 | 286.5 | 307.5 |
|---|---|---|---|---|---|---|---|---|
| Passenger load, lb. | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1920 | 0 | 1 | 5 | 6 | 0 | − 9 | 0 | 22 |
| 3600 | 0 | 4 | 14 | 15 | 6 | −13 | 0 | 41 |
| 5280 | 0 | 2 | 12 | 14 | 1 | −28 | 0 | 53 |
| 3600 | 0 | − 6 | 0 | 2 | −4 | −31 | 0 | 53 |
| 1920 | 0 | −10 | − 6 | − 4 | −3 | −27 | 0 | 43 |
| 0 | 0 | −12 | −14 | −12 | −4 | −16 | 0 | 30 |

The actual data taken are shown in Table 4. These readings were not all taken in the same test. The deflection apparatus was placed under the left side of the bus, the loads applied, and the readings taken. The apparatus was then placed under the right side of the bus, the loads applied again and the readings taken. It will be noted that some of the deflections became negative as the load was released. The authors have reason to believe that the deflection apparatus was sinking slowly during the tests. The apparatus for the test upon the left side was set up late in the afternoon and the test run the next day. It was noted that the apparatus had dropped away from the bus slightly and had to be readjusted. The apparatus for the test upon the right side was set up in the morning and the test run in the afternoon. The data show that the apparatus dropped considerably during the test. The data were corrected for this error by distributing the total drop at each deflection point evenly over the deflection readings taken at that point. The result of this correction is shown in Table 5.

TABLE 5 DEFLECTION DATA CORRECTED FOR DROP OF DEFLECTION APPARATUS

(Deflections shown in thousandths of an inch, positive downward.)

Left side facing forward

| Distance from front, in. | 0 | 55 | 92 | 130.5 | 180 | 220.75 | 286.5 | 306.5 |
|---|---|---|---|---|---|---|---|---|
| Passenger load, lb. | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1920 | 0 | 19 | 30 | 32 | 25 | 20 | 0 | 19 |
| 3600 | 0 | 49 | 66 | 76 | 65 | 53 | 0 | 50 |
| 5280 | 0 | 74 | 85 | 95 | 79 | 71 | 0 | 57 |
| 3600 | 0 | 59 | 64 | 72 | 59 | ... | 0 | 38 |
| 1920 | 0 | 38 | 39 | 43 | 36 | 24 | 0 | 20 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Right side facing forward

| Distance from front, in. | 0 | 53 | 94 | 131 | 179 | 222 | 286.5 | 307.5 |
|---|---|---|---|---|---|---|---|---|
| Passenger load, lb. | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1920 | 0 | 3 | 7 | 8 | 1 | − 6 | 0 | 17 |
| 3600 | 0 | 8 | 17 | 19 | 7 | − 7 | 0 | 31 |
| 5280 | 0 | 8 | 17 | 20 | 3 | −19 | 0 | 38 |
| 3600 | 0 | 2 | 8 | 10 | −1 | −19 | 0 | 33 |
| 1920 | 0 | 0 | 5 | 6 | 1 | −12 | 0 | 18 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The average deflection readings shown in Table 6 were analyzed by the experimental method outlined in the body of the paper. The deflection curves were plotted to scales which made the maximum deflection about 3 in. Small steel open rings made from screw eyes were used to connect the rubber bands to light silk fish line which in turn was fastened to the model beams and to nails driven into the blackboard (see Fig. 1). A sufficient number of rubber bands was used at each load point to keep the maximum elongation under $2^1/_2$ times their free length. A bright electric light was placed in front of the blackboard about 25 ft. from it. The rubber bands were adjusted until the shadow of the beam coincided with the points plotted upon the blackboard. It was found more convenient to measure the length of the shadow of the rubber bands than to measure the bands themselves. These measurements were made to the nearest hundredth of an inch.

The rubber bands were released from the model beam and each group loaded separately by means of a scale pan and gram weights. This apparatus was also supported in front of the blackboard and the

shadow of the group of rubber bands again measured. It was noted that when a group of bands was loaded the deflection increased for a few minutes after the load was applied, but finally became constant. Therefore care was taken to allow the bands sufficient time to adjust themselves to the load. The whole process of loading the model beam and determining the forces was repeated four times for each side of the bus. After each the model beam was reversed so that the curvature at each point would be in the opposite direction. After these readings were taken the model beam was cut at points midway between the load points and these sections weighed. The loads obtained corrected for both the weights of the beam sections and the weights of the steel open rings are shown in Table 7. It will be noted in Fig. 1 that the apparatus was arranged so as to give the correct ratio of load at the points corresponding to the spring fastenings. This ratio is determined by the dimensions of the springs.

An idea of the accuracy of the average results was obtained by comparing the sum of all the upward forces to the sum of all the downward forces. These two sums should be equal since the model beam was in equilibrium. The comparison is given at the foot of Table 7. Tables 2 and 3 were obtained directly from Table 7.

TABLE 6 DEFLECTION DATA REDUCED TO A 3600-LB. LOAD

(Deflections shown in thousandths of an inch, positive downward.)

Left side facing forward

| Distance from front, in. | 0 | 55 | 92 | 130.5 | 180 | 220.75 | 285.6 | 306.5 |
|---|---|---|---|---|---|---|---|---|
| Load at which readings were taken, lb. | | | | | | | | |
| 1920 | 0 | 53 | 64 | 69 | 56 | 41 | 0 | 38 |
| 3600 | 0 | 54 | 65 | 74 | 62 | 53 | 0 | 44 |
| 5280 | 0 | 50 | 58 | 65 | 54 | 48 | 0 | 39 |
| Average | 0 | 52.3 | 62.3 | 69.3 | 57.3 | 47.3 | 0 | 40.3 |
| Probable error of average | 0 | 0.8 | 1.5 | 1.8 | 1.6 | 2.3 | 0 | 1.3 |

Right side facing forward

| Distance from front, in. | 0 | 55 | 94 | 131 | 179 | 222 | 286.5 | 307.5 |
|---|---|---|---|---|---|---|---|---|
| Load at which readings were taken, lb. | | | | | | | | |
| 1920 | 0 | 4 | 11 | 13 | 2 | −17 | 0 | 34 |
| 3600 | 0 | 5 | 12 | 14 | 3 | −13 | 0 | 32 |
| 5280 | 0 | 5 | 12 | 14 | 2 | −13 | 0 | 26 |
| Average | 0 | 4.7 | 11.7 | 13.7 | 2.3 | −14.3 | 0 | 30.7 |
| Probable error of average | 0 | 0.3 | 0.3 | 0.3 | 0.3 | 0.8 | 0 | 1.7 |

TABLE 7 OBSERVED FORCES UPON MODEL BEAM IN GRAMS

| Station letter | $R_1$ | $R_1$ | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $R_2$ | $R_2$ | $P_5$ | $P_6$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Distance from front in $^1/_4$ in. | 0 | 55 | 88 | 125 | 185 | 219.5 | 226.5 | 286.5 | 289.5 | 338 |
| Left side | | | | | | | | | | |
| Test No. | | | | | | | | | | |
| 1 | −54.5 | −54.5 | 244 | −103 | − 442 | 1840 | − 996 | − 996 | 0 | 454 |
| 2 | −38.5 | −38.5 | 184 | − 39 | − 619 | 2078 | −1015 | −1015 | 0 | 446 |
| 3 | −44.5 | −44.5 | 144 | 30 | − 552 | 1830 | − 891 | − 891 | 0 | 429 |
| 4 | −40.5 | −40.5 | 183 | − 28 | − 687 | 2188 | −1014.5 | −1014.5 | 0 | 474 |
| Sum | −178 | −178 | 755 | −140 | −2300 | 7936 | −3916.5 | −3916.5 | 0 | 1803 |
| Right side | | | | | | | | | | |
| 1 | 8 | − 8 | −235 | 239 | 149 | 1173 | −1242.5 | −1242.5 | 694 | 379 |
| 2 | −11.5 | −11.5 | −185 | 209 | 59 | 1380 | −1373.5 | −1373.5 | 844 | 358 |
| 3 | −13.5 | −13.5 | −193 | 236 | 84 | 1241 | −1307 | −1307 | 699 | 389 |
| 4 | − 8 | − 8 | −123 | 116 | 72 | 1415 | −1272 | −1272 | 629 | 414 |
| Sum | −42 | −42 | −736 | 800 | 364 | 5209 | −5195 | −5195 | 2866 | 1540 |

Left side

| | |
|---|---|
| Sum of all upward forces | 10,514 grams |
| Sum of all downward forces | 10,659 grams |
| Difference | 145 grams |

Right side

| | |
|---|---|
| Sum of all upward forces | 10,779 grams |
| Sum of all downward forces | 10,794 grams |
| Difference | 15 grams |

## Discussion

S. Madsen.[3] This test evidently has been applied to only one type of bus body. Do these calculations apply to other automobile bodies such as moving vans? To get proper stiffness in bus bodies, are wood and steel used in modern construction?

Charles B. Norris. The calculations in the paper are confined to one bus body; not alone to one type, but to one particular body. However, the same method of calculation could be applied by any bus-body engineer to any type of bus body.

The method is of value where, because of its depth, the body is very stiff, and where, because of complicated design, it is difficult to compute the elastic properties of the body and therefore difficult to determine the distribution of the forces upon it. However, the method is applicable to the analysis of any body supported upon a chassis of known elastic properties.

As to types of construction, the bus industry is in a rather chaotic state. There are buses of all kinds. One type of bus is built entirely of aluminum in which there is no chassis at all. The chassis is built into the bus body itself with regular bridge construction. There are types of metal bus bodies built of small T-sections, and depending upon the side paneling for rigidity. The panels are made of steel, aluminum, plywood, and plywood covered with steel. Other bodies are built entirely of wood with the members glued and screwed together.

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# Investigation of the Pulp and Paper Industry in the State of Washington

By BRUCE WALLACE ROSS[1] and SEICHI KONZO,[1] SEATTLE, WASH.

*In this paper the authors discuss the pulp- and paper-manufacturing industry as it is conducted today and show that, owing to location, source of supply, water supply for both power and process, labor, etc., the state of Washington presents many attractions to the prospective plant builder.*

*Of the subjects taken up, the first has to do with the materials used in the manufacture of paper. Then the several species of woods found in the United States, with particular emphasis on the state of Washington, are discussed, together with statistics concerning quantities available. One of the sources of supply mentioned is mill waste, and the possibilities of carrying on pulp operations in co-operation with saw-mill activities are discussed.*

*Pulp-making processes also are treated, those receiving attention being the mechanical process, the soda chemical process, the sulphate process, and the sulphite process.*

*The process of making paper is touched upon, but owing to the fact that complete treatises on this subject may be obtained without difficulty, little more than a brief review is given.*

*Interesting statistics on the consumption of wood pulp, its production in the United States, particularly in Washington, and its exportation appear in the paper.*

AT PRESENT there is a wide-spread belief that the paper of the future will be made of some material other than wood pulp. From time to time there have been discoveries, or rediscoveries, of other paper-making materials, but in each case there has been present some factor which has prevented the marketing of the product on a basis competitive with that of paper made from wood pulp. The two principal reasons are the cost of production and the source of raw materials.

### Materials Used in the Manufacture of Paper

A good, strong, high-grade paper is made from linen and high-grade cotton rags, and is used in the manufacture of book and stationery paper. But even in the case of this paper, probably the strongest competitor of that derived from wood pulp, it has been found to be more advantageous to add a portion of wood pulp to the raw material. The raw material is anything but abundant, the United States being largely dependent upon foreign countries for its supply. The lower grades of cotton rags are used in the manufacture of building felt and sheathing paper. Manila stock is used in the manufacture of a strong, tough, fiber paper demanded by heavy products, such as containers for cement, etc. Since the World War, cotton linters have been used in the manufacture of book paper, but this has been done to supplement the rag supply rather than to enter into active competition with the wood-pulp product. Straw has entered into the paper industry to a considerable extent in the manufacture of corrugated boards. Bagasse, kelp, corn stalks, the fibrous waste from other industries, together with a long list of plants, have been tried for paper, as have even the soft and fibrous minerals. The use of these different materials in the manufacture of paper has increased with the passing of time, but in no way has their increase kept pace with the increase of wood pulp. In practically every case the production cost has been made the deciding factor in the determination of the feasibility of manufacturing the raw material into paper. Seasonal crops and the relatively low yield per unit of pulping material have, along with the transportation and storage problem, been influential in the abandonment of these fibrous materials as possible sources of supply for paper manufacture. Despite the fact that wood is a comparative newcomer in the pulp world, it is almost certain from past experience and present knowledge that it will be the predominating factor in the future pulp and paper industry. Furthermore, the paper industry has become accustomed to handling wood-pulp paper, and paper from other materials would not be readily accepted.

### Species and Quantities of Wood

*In the United States.* The area of forest land in the United States has in the past three centuries decreased from some 822 million acres to approximately 470 million. There is no way of determining the actual quantity of pulp-wood timber which is now standing, as this quantity varies from month to month, and in the newer parts of the country is more or less dependent upon the lumber industry, fires, etc. In 1870, only a little over fifty years ago, there was no material amount of wood used for paper pulp.

The United States, with respect to the timber supply, is generally divided into nine groups of states: the New England States, the Middle Atlantic States, the South Atlantic and Gulf, the Lake, the Central, the Lower Mississippi, the Rocky Mountain, and the Pacific Coast States. The total standing pulp species in million cords in each of these groups is shown in Table 1.

TABLE 1 QUANTITY OF STANDING TIMBER IN THE UNITED STATES BY REGIONS

| Region | Total standing pulp species in million cords |
|---|---|
| New England | 166.9 |
| Middle Atlantic | 162.9 |
| Lake | 330.8 |
| Central | 241.0 |
| South Atlantic | 611.5 |
| Lower Mississippi | 678.0 |
| Rocky Mountain | 442.7 |
| Pacific Coast | 897.4 |
| Total United States Proper | 3530.9 |
| Southeast Alaska | 167.0 |

The above figures do not contain the allowance for reduction in stand by the spruce bud worm, which amounts to 40 per cent, or about 27½ million cords in Maine.

The future supply of pulp wood depends almost entirely on the amount and success of reforestation, which is at present undergoing intensive study by the Federal Government, by the different state governments, and by the timber-owning private firms. At present the Southern States have the greatest stand of timber suitable for the manufacture of pulp, having an estimated quantity of about 1250 million cords. The Pacific Coast States have the next greatest amount with an estimated cordage of 850 million, while the Rocky Mountain States have an estimated 400 million cords. Each of the remaining state groups have less than 200 million cords available. In the Middle Atlantic States there has been a gradual depletion of the supplies of pulp timber, as in the New England and Southern States, and from present aspects it will be but a short time until the

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production of pulp will have to be curtailed, some new pulping process developed for species not now used, or some means found of speeding the second-growth timber.

At the present time there is a temporary stimulus to the use of the better grades of timber for the pulp industry in the Eastern States, due to their inability to meet the market price of the western Douglas fir in the sawmill market. It is possible under existing conditions for the West Coast lumberman to deliver his products on the Atlantic Coast at a lower price than the Eastern lumber manufacturers can. This has resulted in a condition whereby the pulp industry in those localities receives the timber that would ordinarily be routed to the lumber mills.

*In Washington.* It is only natural in the carrying on of the pulp and paper industry that as the resources are exhausted the manufacturers will turn to the locality with the greatest stand of spruce, fir and hemlock, since 78 per cent of our requirements depend upon these species; and it is especially advantageous to enter into a virgin timber country which can support the industry while reforestation is going on. Alaska and the Pacific Coast States offer exceptional opportunities in this respect. At the present time the Government is offering every inducement to manufacturers to establish the industry in Alaska, assuring them of pulp timber at a reasonable cost as far ahead as 1942.

The Pacific Coast States offer innumerable inducements for the establishment of the industry. Washington, Oregon, and California are the three states of the Pacific Coast group, and they possess about one-half of the remaining saw timber in the United States. They have about one-fourth of the stand of pulp species, in cords. Some sources of information state that one-half of the remaining virgin forest of the United States is in the vicinity of Puget Sound, and give the stand of Douglas fir alone in a belt 100 miles wide and 350 miles along the coast as 960 billion feet. Table 2 gives some interesting figures on the species of timber west of the Rocky Mountains.

TABLE 2 SPECIES OF TIMBER WEST OF THE ROCKY MOUNTAINS ACCORDING TO THE 1920 FOREST SERVICE REPORT

| | Million bd. ft. |
|---|---|
| Douglas fir | 558,571 |
| Western yellow pine | 183,453 |
| West-Coast hemlock | 94,000 |
| True firs | 82,479 |
| Redwood | 72,208 |
| Western red cedar | 49,000 |
| Miscellaneous varieties | 44,914 |
| Sugar and western white pine | 38,483 |
| Sitka spruce | 13,355 |
| Lodgepole pine | 4,566 |
| Total | 1,141,031 |

The timber in California differs in species from that in Washington, and the available quantity is somewhat smaller. The total stand of timber in Oregon is greater than that of Washington, but the percentage of pulp species is smaller, and due to the development of the country the available timber in Washington greatly exceeds that of Oregon. Table 3 is interesting in this connection. With the exception of one year, the volume of lumber cut in Washington has exceeded that of any other state since 1905, which has resulted in the greatest advancement of logging operations found anywhere in the world.

TABLE 3 TIMBER STAND BY SPECIES IN THREE WESTERN STATES

(From 1923 report of the Senate Reforestation Comm.)

| Species | California | Oregon | Washington |
|---|---|---|---|
| Western yellow and white pine | 77,176,000 | 75,549,759 | 13,731,367 |
| Sugar pine | 31,928,000 | | |
| Douglas fir | 39,114,000 | 245,797,056 | 135,860,853 |
| Redwood | 70,000,000 | | |
| All others | 66,287,000 | 74,429,414 | 133,053,262 |
| Totals | 284,505,000 | 395,776,229 | 282,645,481 |

When it is considered that one-fourth of the remaining pulp wood is in these three states and that Washington has more than her share of this commodity, considered with the fact that the timber stand is more localized in this state than in others, the wonderful possibilities of the development of the pulp industry in this section of the country are realized. Some sources of information give the fact that in most parts of the country the average cut of pulp wood is five cords per acre, while that of western Washington is in the neighborhood of 20 to 40 cords per acre, and frequently much more. It has also been found that in this section of the country two cords of pulp wood are equivalent to three cords of the eastern pulp wood, this fact being due to the marked superiority of the western woods over the eastern with respect to size, lack of knots, and clearness. It is estimated that on each acre of logged-off land there are at least ten cords of pulp wood left to rot, due to the fact that there are relatively few pulp mills in this vicinity now, and also to the fact that there is no advantage to the manufacturer in securing such wood when the cheapness of other supplies of pulp wood is considered. When the total acreage of logged-off land is considered, together with the startling fact that for each acre of this land there are ten cords available at a cost involving little more than the cost of transportation, the immensity of the raw-material supply and the relative low cost may be comprehended.

In 1924 in the state of Washington there was a forest area of somewhere in the neighborhood of 12,000,000 acres containing 282,645,000,000 bd.ft. of merchantable timber divided up as follows:

| | |
|---|---|
| Privately owned | 173,350,000,000 bd.ft. |
| State owned | 23,027,000,000 bd.ft. |
| Federal owned | 86,268,481,000 bd.ft. |

The timber owners in the state number 12,000, and their average holdings run about 470 acres.

In 1924, from the different cruises in the different counties taken as a basis, Table 4 was compiled for the percentage of the total stand with respect to the different species. This percentage, of course, does not hold true for each county, but it does give a good idea of the relative stands with respect to each other. For instance, there is a strip some 30 miles wide along the ocean side of the Olympic peninsula which is practically all spruce. The hemlock is found mixed in with the Douglas fir, and usually grows at an altitude of less than 2500 ft. Between the 2500- and 3500-ft. contours is found the hemlock-silver fir type, and above this range is found the silver fir and western hemlock species. As the altitude increases the quantity and the quality of the timber decreases.

TABLE 4 SPECIES OF WOOD BY PERCENTAGE

| Scientific name | Common name | Percentage |
|---|---|---|
| Pseudotsuga Taxifolia | Douglas fir | 46 |
| Tsuga Heterophylla | Western hemlock | 21 |
| Thuga Plicata | Western red cedar | 12 |
| Pinus Ponderosa | Western yellow pine | 7 |
| Abies Nobilis | Silver-Noble fir | 5 |
| Pica Stichensis | Sitka spruce | 4 |
| Larix Occidentalis | Western larch | 2 |
| Pinus Monticola | Western white pine | 1 |
| All others not including cotton wood | | 2 |

In 1920 a survey was made by the government on the possibility of securing wood pulp in the northwest portion of the Northwest, and it was found that 635,000 cords of pulp wood could be obtained from the operations designed primarily for the lumber industry, neglecting the possibility of obtaining smaller and broken trees unfit for the lumber industry, but suitable for pulp manufacture. In considering the reforestation problem it is noticed that the possible growth in the Pacific Northwest is much faster than in the other sections of the country. While the average possible growth under intensive forestry for the spruce-fir type in the Northeast as a whole is estimated as 45 cu. ft. per acre per year, and in the Lake states as 35 cu. ft. per

acre per year, it is placed at 112 cu. ft. in the Northwest. In the Pacific states the minimum rotation of crops is placed at 30 years, as compared with 50 years for that of the Eastern states.

### Pulping Quality of Washington Timber

Species of trees vary over the United States and are quite definitely bounded within limited territories. In the state of Washington the species are limited, and this division is even more complete in that the Cascade Mountains make another quite definite boundary line for the different species. In the western part of the state the so-called Douglas fir predominates, with considerable stands of spruce, fir, and larch also existing.

A great deal has not been done up to the present time toward the development of the Douglas fir as a pulp wood. The saw-log value has been so high and the timber has been in such demand that the price has been prohibitive for the manufacture of pulp. As time goes on, however, it is being found that it is more and more profitable to operate the logging industry of the pulp woods in conjunction with that of the saw logs, and to go over the cut-off, saw-log lands for pulp wood. In the earlier stages of the logging operations in this country a great deal of the less desirable timber, which would be suitable for pulp wood, was left standing. In the determination of the desirability of wood for pulp it is found that there is a peculiar feature in some woods in the direction or density of the grain or fiber of the wood which adds much to the value of the tree possessing it. It is called the strength of fiber, and is the characteristic or quality of the wood which fits it for the manufacture of pulp from which paper, celluloid, card board, etc., are made. Poplars stand at the head of the list in the possession of this quality. Spruce is next, although the poplar and trembling aspen have slightly superior merits for the manufacture of pulp wood. Spruce is one of the predominating stands in Washington. Sitka spruce or Picea Stichensis is found along the entire Pacific Coast, the major growths extending inland for some 50 or more miles. Sitka spruce ranks very well with white spruce, the standard pulp wood of North America. Western hemlock outranks it at the present time in consumption on the Pacific Coast only because of the keen competition with the sawmills for the spruce logs, and the suitability of the less expensive hemlock for newsprint. At present one-half of the pulp wood consumed on the Pacific Coast is Western hemlock, which is largely used in the making of newsprint, but is also suitable for other paper uses.

### Study of Washington Timber Species

The yield of pulp from any given wood depends upon the specific gravity of the wood, the weight per cubic foot, and the pulping method employed. Below will be found an outline, which is taken from a bulletin of the Forest Products Laboratory at Madison, Wis., giving the pulping qualities of the different species found in the Northwest. In considering the pulping qualities and other data given for the different woods, attention is drawn to the following points:

1 The weights of wood given are for bone-dry material per solid cubic foot. This is obtained by multiplying the specific gravity of the oven-dried wood, based on the green volume, by 62.3 lb. (the weight of a cubic foot of water).

2 The fiber lengths as given are the average of all the available data taken from the Forest Service investigations and from other sources. Many of the measurements given are the results of averages of thousands of determinations; in other cases, from only a few determinations.

3 The yield figures represent the yield of bone-dry screened and unbleached pulp per hundred cubic feet of solid bone-dry wood. For the purposes of this article, it has been assumed that the ordinary cord of wood (rossed) piled 4 ft. by 4 ft. by 8 ft. is equivalent to 100 solid cu. ft. of wood. To convert the yields on bone-dry basis to air-dry pulp containing 10 per cent moisture, divide the yield by 0.9.

The yield data are based on results obtained from experimental runs made under very favorable conditions. The pulp logs on arrival at the laboratory are barked, sawed to convenient size, and any wood containing knots and decayed spots is rejected. The chips are carefully sorted and are far more uniform in size and moisture content than can be obtained in commercial practice, unless the mills operate under more favorable conditions than ordinarily exist. Further, each cook representing an individual experiment, it is possible to press, shred, sample and screen the pulp with fewer mechanical losses than is feasible in handling the pulp in commercial practice from the blow pit to the wet machine or to the finished paper.

4 The comparison of the character and uses of the various pulps that may be obtained from the different woods offers certain difficulties. It has, therefore, been decided to consider white spruce as the standard wood for pulping by the sulphite, sulphate, and mechanical processes, and to compare the pulp that might be obtained from any given wood by this process of pulping with the pulp obtained from white spruce. Aspen wood has likewise been adopted as the standard for reduction by the soda process, and soda pulps from other woods will be compared with it. Sulphate pulps made from deciduous woods bleach with greater ease and economy than the corresponding soda pulps.

*DOUGLAS FIR—Pseudotsuga Taxifolia*—Weight, 28 lb.; fiber, 4.4 mm.

- Sulphite pulp—Yield, 1200 lb.; character, hard to pulp, difficult to bleach, fair strength, poor color, pitchy; possible uses, few.
- Sulphate pulp—Yield, 1170 lb.; character, good grade of kraft pulp, but not as strong as white spruce; possible uses, similar to white spruce.
- Mechanical pulp—Because of high pitch content is probably unsuitable for this purpose.

*WESTERN YELLOW PINE—Pinus Ponderosa*—Weight, 24 lb.; fiber, 3.6 mm.

- Sulphite pulp—Yield, 1130 lb.; character, not difficult to pulp, difficult to bleach, shivey, very poor strength and color; possible uses, few.
- Sulphate pulp—Yield, 1100 lb.; character, fairly easily bleached, fine, high grade, very strong, and tough fiber; possible uses, same as white spruce.
- Mechanical pulp—Yield, 2060 lb.; character, fibers long, coarse, soft, creamy color, pitchy; possible uses, medium quality of groundwood.

*WESTERN HEMLOCK—Tsuga Heterophylla*—Weight, 23 lb.; fiber, 2.7 mm.

- Sulphite pulp—Yield, 1050 lb.; character, easily pulped, easily bleached, good strength, fair color; possible uses, same as white spruce.
- Sulphate pulp—Yield, 1100 lb.; character, good strong fiber; possible uses, similar to white spruce.
- Mechanical pulp—Yield, 2160 lb.; character, good strength and fiber, grayish color; possible uses, similar to white spruce.

*NOBLE FIR—Abies Nobilis*—Weight, 22 lb.; fiber, no data.

- Sulphite pulp—Yield, 1010 lb.; character, easily pulped and bleached, fair strength, excellent color; possible uses, substitute for white spruce.
- Sulphate pulp—Yield, 1080 lb.; character, good quality of strong pulp; possible uses, substitute for white spruce.
- Mechanical pulp—Yield, 1920 lb.; character, good color, long strong fiber; possible uses, same as white spruce.

*SILVER FIR—Abies Amabilis*—Weight, 22 lb.; fiber, no data.
Sulphite pulp—Yield, 1060 lb.; character, easily pulped and bleached, fair strength, good color; possible uses, same as white spruce.

*SITKA SPRUCE—Picea Sitchensis*—Weight, 24 lb.; fiber, 3.5 mm.
Sulphite pulp—Yield, 1080 lb.; character, easily pulped and bleached, excellent strength and color; possible uses, same as white spruce.
Sulphate pulp—Yield, 1150 lb.; same as white spruce.
Mechanical pulp—Yield, 2040 lb.; same as white spruce.

*WESTERN RED CEDAR—Thuja Plicata*—Weight, 19 lb.; fiber, 3.8 mm.
Sulphite pulp—Yield, 830 lb.; character, difficult to bleach, dark color but fair strength; possible uses, few.
Sulphate pulp—Yield, 830 lb.; character, rather difficult to bleach, fair strength; possible uses, same as white spruce.

*WESTERN LARCH—Larix Occidentalis*—Weight, 28 lb.; fiber, 2.6 mm.
Sulphite pulp—Yield, 1200 lb.; character, difficult to pulp and bleach, poor strength and color; possible uses, low grade wrappings.
Sulphate pulp—Yield, 1290 lb.; character, good quality of kraft fiber; possible uses, same as white spruce.
Mechanical pulp—Yield, 2100 lb.; character, brown color, short fiber, fair strength; possible uses, medium quality groundwood.

*LOWLAND WHITE FIR—Abies grandis*—Weight, 23 lb.; fiber, 3.2 mm.
Sulphite pulp—Yield, 980 lb.; character, easily pulped and bleached, fair strength, excellent color; possible uses, substitute for white spruce.
Sulphate pulp—Yield, 1140 lb.; character, good strong grade of kraft pulp; possible uses, same as white spruce.
Mechanical pulp—Yield, 1950 lb.; character, good strength, color and fiber; possible uses, same as white spruce.

*PORT ORFORD CEDAR—Chamaecyparis lawsoniana*—Weight, 26 lb.; fiber, 3.5 mm.
Sulphite pulp—Yield, 1150 lb.; character, fairly easily pulped, rather difficult to bleach, fair strength and color; possible uses, same as white spruce.

*ENGELMANN SPRUCE—Picea engelmanni*—Weight, 21 lb.; fiber, no data.
Sulphite pulp—Yield, 990 lb.; character, a little hard to pulp, excellent strength and color; possible uses, same as white spruce.
Sulphate pulp—Yield, 1000 lb.; character and possible uses, similar to white spruce.
Mechanical pulp—Yield, 2000 lb.; character, strong fiber of good color; possible uses, same as white spruce.

*LODGEPOLE PINE—Pinus murrayana*—Weight, 24 lb.; fiber, 2.3 mm.
Sulphite pulp—Yield, 1080 lb.; character, easily pulped, a little hard to bleach, excellent strength and color; possible uses, substitute for white spruce.
Sulphate pulp—Yield, 1120 lb.; character and uses, same as white spruce.
Mechanical pulp—Yield, 2140 lb.; character and uses, a little pitchy but otherwise same as white spruce.

*RED ALDER—Alnus Oregona*—Weight, 23 lb.; fiber, 1.2 mm.
Soda pulp—Yield, 1160 lb.; character, soft, harder to bleach than aspen; possible uses, same as aspen.
Mechanical pulp—probably same as aspen.

*PAPER BIRCH—Betula papyrifera*—Weight, 34 lb.; fiber, 1.2 mm.
Sulphite pulp—Yield, 1500 lb.; character, easily pulped, difficult to bleach, poor strength and color; possible uses, few.
Soda pulp—Yield, 1350 lb.; character, more difficult to reduce than aspen, soft, easily bleached; possible uses, similar to aspen.
Mechanical pulp—Yield, 3000 lb.; character, short fiber and poor strength, pinkish color; possible uses, as a filler with long-fibered stock.

*COTTONWOOD—Populus deltoides*—Weight, 23 lb.; fiber, 1.3 mm.
Sulphite pulp—Yield, 1035 lb.; character, easily pulped and bleached, very weak, excellent color; possible uses, same as aspen.
Soda pulp—Yield, 1030 lb.; character, soft and easily bleached.
Mechanical pulp—Yield, 2180 lb.; possible uses, as a filler when used with longer-fibered stocks; character, weak, short fibered, color good.

### Mill Waste as Raw Material

The use of logging and sawmill waste as a pulping material a few years ago was on the decline in the United States. This was accounted for by the fact that, in the past, the operation of a sawmill in any one place was more or less temporary. Also, the entrance of the pulping industry has hurried the departure of the sawmill from that locality, resulting in the loss of source of waste. There existed no association between the owners of the lumber-manufacturing concerns and those of the pulp mills which tended to raise the price of mill waste. When the time comes, however, that the pulp operations can be carried on in cooperation with sawmill operations, unsuitable logs and waste from the mills can be utilized cheaply for pulp purposes, and, as it has been found in Sweden, the price of manufacture will show a sharp decrease. About 8 per cent of the total wood now used in the industry is in the form of waste. At present this consists of hemlock and spruce slabs, and other large pieces, cut from peeled logs and freed from bark. There are at the present time several mills in the South which are operating exclusively on yellow-pine waste. On the West Coast there have been constructed during the past few years several large permanent sawmills, and quite a few of these have seen fit to add pulp mills, or have made provisions in their programs of expansion to include pulp mills in their scheme of operation.

### Power

The major considerations of the location of any industrial operation are: labor, market, power, and raw materials. In the case of the pulp industry the excessive freight rates on the pulp wood makes it necessary that the pulp mill be located in the vicinity of the raw materials. This fact brings up the question of suitable power at a practical cost. From a census taken of the different mills throughout the United States, and based on the ratings of the prime movers, it was found that about 85 per cent were electric motors. Of these, some 35 per cent were operated on purchased current and 65 per cent on current generated at the mills. Washington is one of the leading states in both the production of water power and in potential supply. Government geological data give the fact that one-sixth of the nation's supply is situated in the vicinity of Puget Sound. Very satisfactory rates may be had from the power companies now in operation; some mills now in operation are obtaining a rate of 4 mills per kw-hr. At practically all points of logical mill sites power may be manufactured in sufficient quantities for all mill needs. Due to the great number of saw mills, hog fuel may be obtained at a nominal rate, and the state possesses enough coal to last the nation some 125 years. The coal mined may not be of the highest quality, but it is comparatively cheap.

### Labor, Chemical Supply, Etc.

Washington has been the leading lumber-producing state since 1905, which assures the labor supply in so far as the logging end of the industry is concerned. There are at the present time pulp and paper mills in operation and little difficulty has been experienced in the lack of labor. The temperate climate also is tending to keep the labor turnover at a minimum.

In considering the materials needed for the chemical processes, it has been found that they are all easily available. Eastern Washington has great deposits of sodium sulphite, sulphur is found in sufficient quantities in Alaska, and native lime rock is found in most parts of the state.

### Water Supply

Water is another factor which plays an important part in the manufacture of paper. It is demanded in immense quantities, and many mills require 400,000 gal. of water per ton of product. It serves as a solvent and a carrier of chemicals in the digesters and cookers, it conveys the pulp through the various machines, and it is used in the boilers and heaters. The water supply is usually treated to remove suspended and organic matter, particularly living organisms. Much suspended matter causes irregularities in the texture and the appearance of the finer grades of paper, it clogs the screens of the different machines, and it also causes excess waste of the bleach and bisulphite liquors. Iron is very undesirable. Soft water is undesirable, due to the solubility of any form of calcium sulphate and the resulting waste that the mixture causes. Hard water deposits calcium carbonate on the screens used to separate the pulp from the liquors, and interferes in the sizing operation.

In a survey made by the Department of the Interior, a summary of the report states that an estimated 95 per cent of the river waters of the state are suitable for industrial purposes, and that they are unusually low in mineral content, having little suspended matter. Table 5 gives the chemical analysis of the principal rivers of the state.

TABLE 5 SURFACE WATERS OF WASHINGTON—MINERAL CONTENT IN PARTS PER MILLION

| River | Locality | Turbidity | Suspended matter | Coefficient of fineness | Silica ($SiO_2$) | Iron (Fe) | Calcium (Ca) | Magnesium (Mg) | Sodium and potassium (Na + K) | Carbonate radicle ($CO_3$) | Bicarbonate radicle ($HCO_3$) | Sulphate radicle ($SO_4$) | Nitrate radicle ($NO_3$) | Chlorine (Cl) | Total solids |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cedar | Ravendale | 5 | 4.2 | 0.74 | 13 | 0.02 | 6.7 | 1.4 | 3.6 | 0.0 | 28 | 5.7 | 0.20 | 1.2 | 49 |
| Chehalis | Centralia | 17 | 18 | 1.01 | 16 | 0.08 | 7.1 | 1.9 | 6.5 | 0.0 | 31 | 6.4 | 0.10 | 5.2 | 63 |
| Columbia | Northport | 5 | 4.7 | 1.07 | 8.7 | 0.02 | 18 | 4.7 | 4.7 | 0.0 | 73 | 12 | 0.23 | 0.6 | 84 |
| Columbia | Pasco | 9 | 6.7 | 0.70 | 7.7 | 0.04 | 18 | 4.5 | 6.0 | 0.0 | 73 | 11 | 0.14 | 0.7 | 83 |
| Green | Hot Springs | 6 | 7.0 | 1.10 | 17 | 0.04 | 6.0 | 1.3 | 5.6 | 0.0 | 28 | 5.9 | 0.13 | 1.3 | 55 |
| Klickitat | Klickitat | 15 | 15 | 1.08 | 27 | 0.13 | 7.1 | 3.2 | 6.6 | 0.0 | 44 | 7.2 | 0.15 | 1.2 | 79 |
| Naches | Naches | 27 | 29 | 1.04 | 23 | 0.08 | 8.2 | 2.5 | 6.1 | 0.0 | 43 | 5.9 | 0.08 | 0.4 | 71 |
| Okanogan | Okanogan | 25 | 24 | 1.21 | 14 | 0.02 | 21 | 4.6 | 8.5 | 0.0 | 81 | 16 | 0.28 | 0.8 | 110 |
| Snake | Burbank | 42 | 52 | 1.76 | 19 | 0.05 | 19 | 5.6 | 14 | 0.0 | 83 | 21 | 0.53 | 8.1 | 131 |
| Spokane | Spokane | 5 | 4.1 | 0.79 | 11 | 0.02 | 11 | 3.6 | 5.3 | 0.0 | 48 | 9.2 | 0.23 | 0.6 | 63 |
| Wenatchee | Cashmere | 9 | 7.0 | 0.76 | 12 | 0.03 | 5.5 | 2.3 | 4.2 | 0.0 | 28 | 7.4 | 0.31 | 1.0 | 46 |
| Wood (Creek) | Everett | 10 | 13 | 1.15 | 25 | 0.01 | 8.6 | 4.5 | 7.6 | 0.0 | 51 | 7.8 | 0.31 | 2.9 | 86 |
| Wynoochee | Montesano | 2 | 1.6 | 0.93 | 11 | 0.01 | 8.2 | 2.2 | 4.8 | 0.0 | 36 | 5.7 | 0.29 | 2.1 | 53 |
| Yakima | Clealum | 6 | 5.8 | 1.12 | 9.9 | 0.02 | 6.7 | 2.3 | 3.7 | 0.0 | 32 | 6.2 | 0.25 | 1.6 | 47 |
| Yakima | Prosser | 18 | 17 | 0.94 | 19 | 0.10 | 16 | 6.1 | 14 | 0.0 | 80 | 1 | 0.34 | 5.2 | 123 |

### Pulp-Making Processes

*The Preparation of Pulp Wood.* The processes employed in the manufacture of paper have undergone radical changes since the ancient days when paper making was strictly a hand process, but the fundamental principle involved has changed but little. To produce an even layer of closely intertwined fibrous material that will have strength and that will bear ink was the original concept of the makers of paper, which still holds true to this day. Of course the varied uses to which paper is put now, from the softest of tissues to the roughest of roofing paper, calls for a very much more complicated process involving a thorough understanding of the chemical and mechanical features that come into play.

This technical feature has resulted in much specialization, until now the details of the paper-making industry are thoroughly understood only by those actually engaged in the process, hence the layman must be contented with just a broad outlook on the whole situation. In the following paragraph a brief description of the preparation of pulp from wood by the four principal processes will be given.

The logs as they come to the mill are covered with bark, sand, and mud that must be removed before the wood can be used. The logs are first cut into either two-foot or four-foot bolts and then relieved of their bark by either of the following three methods:

1 In the smaller mills, and in mills handling a pulp wood whose bark can be readily removed, hand methods of removing the bark are used, but in the larger mills, machine methods are employed.

2 In the "barking drum" the four-foot bolts are introduced with water into a horizontal drum (as large as 45 ft. in length and 12 ft. in diameter), which is revolved at a slow speed by means of a gear drive. The drum is made open at the ends with strips of angle iron that project into the interior fastened longitudinally through its length. The rotation of the drum tumbles the wood over and over, and its bark is removed by the friction of the bolts against the rough surface of the drum and against each other. Eighty per cent of the pulp wood is stripped of its bark by this method, the pieces with bark intact being sent through the drum a second time. The cost involved in the process is low, the amount of wood wasted is small, and a large quantity can be handled per day. For this reason drum barking has been universally adopted for the preparation of newsprint wood.

3 In the "barking" or "rossing" process the pulp wood is pressed against a revolving disk about 4 ft. in diameter set with four or six radial blades projecting from its surface. As the disc revolves the wood is turned on its axis by a mechanism, and the bark, together with 10 to 20 per cent of the wood, is removed. The rossed wood is considered a better product than the drum-barked wood, and commands a price a few dollars per cord higher than the latter. The greater waste in the rossed wood is evident, however. Fig. 1 shows diagrammatically the manner in which materials are handled in the average plant up to the grinding process.

In some mills utilizing sawmill waste, two-foot spruce blocks free from bark, knots, and irregularities are used in great proportions. The weight of the pulp wood, in consideration of its transportation cost, is not as vital a factor in the Pacific Northwest as in some other sections of the country where the wood is hauled over some distance. However, where transport by rail at a published rate per 100 lb. is involved the weight of the wood becomes a serious factor, and explains why the barking and rossing plants are frequently located near the timber supply rather than at the mills. The wood is handled in mechanical

splitters at this point to convert it into handier sizes for the coming processes.

*The Manufacture of Mechanical Pulp.* The importance of mechanical pulp in the American paper industry, especially in supplying the demands for cheap newsprint, should not be overlooked. The United States Department of Agriculture issued figures for 1922 showing that "Mechanical pulp made up slightly over 2,580,000 tons of American pulp requirements in 1922, or 44 per cent, and constituted the largest pulp grade. Since, however, the yield per cord by the mechanical process is relatively high in terms of pulp wood, the 1922 requirements for mechanical

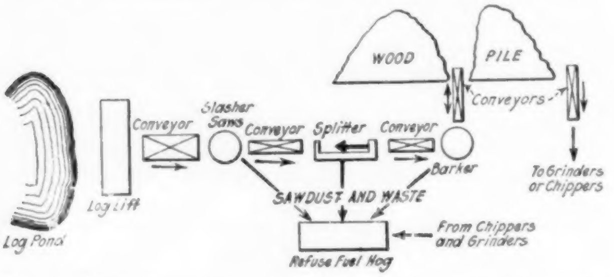


Fig. 1 Flow Diagram from Log Pond to Grinding Room

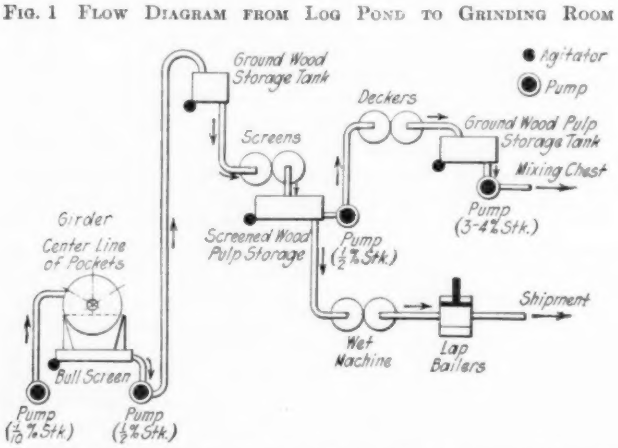


Fig. 2 Flow Diagram of the Mechanical Pulping Process

pulp were slightly less than 2,600,000 cords or only 20 per cent of the total."

The wood species used in the Pacific-Coast region for the mechanical process are largely spruce, cottonwood, and hemlock, with some white fir. Many mills are in operation also whose main source of pulp wood is the wastewood gathered from the lumber mills.

Mechanical pulp alone is very seldom used in the manufacture of paper, but it does form a large percentage of newsprint, paper boards, wrapping paper, etc. The percentage to be added varies all the way from 15 to 80 per cent, depending upon the quality, strength, and the appearance of the paper desired.

In this process the fibrous constituents of the wood are torn apart by mechanical abrasion. The grindstone for the two-foot blocks has a face 27 in. wide and a diameter of 54 in., and is mounted horizontally in a heavy cast-iron box. There are three pockets over its circumference into which the blocks can be placed under a five-ton hydraulic pressure, giving a unit pressure about 40 to 50 lb. per sq. in. In the grinding room of the 25-ton mill at Edmonds, Wash., a 1250-hp., 60-cycle, 3-phase synchronous motor is direct connected to two grinder units, each with three pockets. The stone is rotated at 257 r.p.m. The capacity of the 27-in., 3-pocket grinder is about 8 tons of pulp per 24 hours, on an air-dry basis. Later tendencies have been toward the utilization of 4-ft. bolts on a 54-in. faced grindstone, and with better efficiency. The latest developments, however, have been toward the installation of 4-pocket grinders, which feed the wood in a steady stream from a magazine without losses in time or production.

A stream of water is added continuously to the abrasive surface of the stone. A minimum quantity of water gives a product termed "hot ground" pulp, which is a coarse-fibered pulp resulting from the tearing apart of the wood. The production of the hot-ground pulp is greater than that from the cold-ground pulp, which is produced by adding an excess amount of water to the stone, but the fibers are not as fine or uniform in grade.

The pulp is carried by the flowing water into a chamber below, where it passes through a series of screens. The mesh varies in size from 0.4 in. for the initial screens to 0.012 in. for the finer screens. The fine pulp is carried by the excess water to the wet machine, where it is formed into thick sheets by the removal of

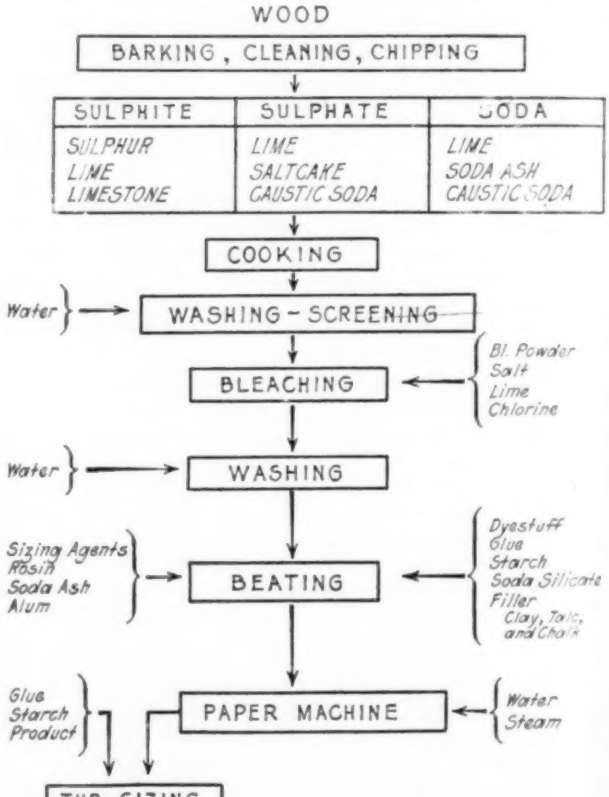


Fig. 3 Diagrammatic Illustration of the Chemical Process of Paper Making

water. Fig. 2 shows in diagram the flow of materials in this process.

The wet machine consists of a partially submerged screen cylinder rotating in a large vat. As the drum rotates the water passes through to the inside of the drum, leaving a thin layer of pulp on the outside of the wire cloth. The layer of pulp is removed from the top of the drum by an endless felt, which is held in close contact with it by means of the pressure from the couch roll, causing the web of the pulp to adhere to the felt. The pulp is wound up on a large wooden cylinder until a good sized sheet is formed, when it is cut across and removed.

The water content at this stage is about 70 per cent, but if shipments are to be made in the form of bales the sheet pulp

is placed with alternate pieces of sacking into a hydraulic press where a fifty per cent air-dry pulp is obtained. (Air-dry pulp is pulp containing 10 per cent moisture, an amount that absolutely air-dry pulp will absorb from the atmosphere.)

As may be expected, the resulting pulp contains practically all the constituents of the original wood, has little strength, and is not of permanent character. Simplicity, however, serves to make the process much cheaper than the chemical processes, and hence it is used whenever the quality of the paper does not demand the finest of pulp stock.

*The Soda Chemical Process.* The diagrammatic sketch of Fig. 3, prepared by A. Krimmel of the Hammermill Paper Company, illustrates the three common chemical processes; namely, soda, sulphite, and sulphate processes. Here are illustrated the main constituents and the processes involved in the manufacture of chemical pulp. In the mechanical process the pulp fibers obtained are identical to the actual composition of the wood itself. In the chemical process, however, the wood is partially dissolved by chemicals, and a fiber of nearly pure cellulose is obtained. All three processes are found on the Pacific Coast, and a high-grade product is being turned out by the mills. In the soda chemical-process mills the prepared bolts of wood from the barking process are carried by conveyors to the chippers, steel or cast iron disks 7 ft. in diameter, set with two or three radial knives on the surface and operating at 200 r.p.m., where they are reduced to chips about $^1/_2$ in. thick. These chips

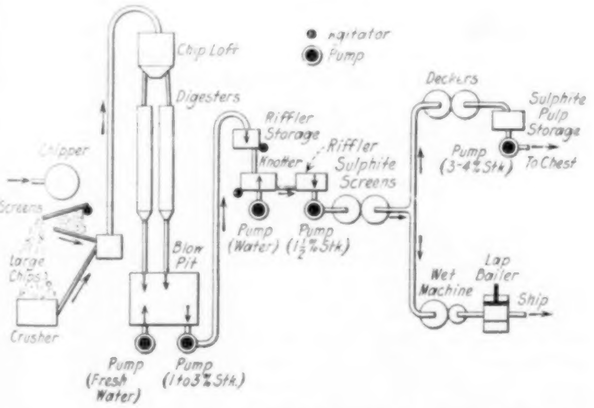


FIG. 4 FLOW DIAGRAM OF THE CHEMICAL PULPING PROCESS

are next broken into smaller pieces by crushers or disintegrators, following which they pass through screens. The screened chips are then carried by conveyor belts to bins directly above and opening into the digesters. The chemical used is sodium hydroxide. High-pressure steam is admitted to the digesters to aid the action of the chemicals. Fig. 4 illustrates the flow of materials through a plant employing the chemical process.

The stationary digester in which the cooking is accomplished is cylindrical in form, 28 ft. high by 7 ft. in diameter, and made of $^1/_2$-in. plates, conically shaped at both top and bottom. The ordinary charge of four cords requires approximately 3500 gal. of liquid, and requires about eight hours for complete digestion. The pulp sludge is then blown into the "blow pit," a large covered tank with a false bottom set about a foot above the inclined permanent bottom. The pulp settles to the false bottom, while the liquid drains through and is pumped to the recovery tank.

A thorough washing is then required to remove the chemicals from the pulp before it is passed to the bleachers. The bleaching operation is performed in a conical basin about 10 ft. high by 5 ft. in diameter, containing an inner cone, at the bottom of which is a mechanically operated screw device which keeps the pulp in a continuous circulation up the inner cone and down the sides while a bleaching solution of CaClOCl which forms HClO in solution.

*The Sulphate Process.* In this process chips about 1 in. to $1^1/_4$ in. in size, together with the liquid digesting solution, are fed into stationary digesters similar to those described in the soda process. The solution used contains sulphur in the form of a sulphide and is alkaline in character. Superheated steam at 440 deg. fahr. and 125 lb. pressure is used in connection with the solution. A thorough washing to remove chemicals follows the completion of cooking. The sulphate process has a distinct advantage in the Pacific Northwest where the resinous woods are found. The sulphate mills being equipped at the present time are utilizing hemlock and fir slab waste from the sawmills, which indicates the importance of this process in the economical utilization of our forest resources. The product classified as "Kraft" pulp is of great strength and is demanded by manufacturers of wrapping paper.

*The Sulphite Process.* The dissociation chemicals used in this

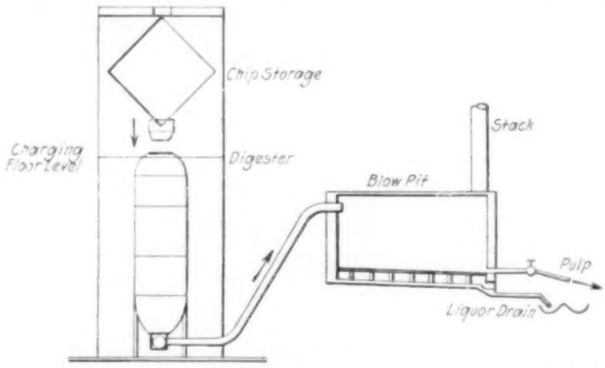


FIG. 5 DIAGRAM OF DIGESTER AND BLOW PIT IN A SULPHITE MILL

process are composed of sulphurous acid and the bisulphites of lime and magnesia. The woods are mainly spruce and hemlock with yields running close to 1000 lb. per cord. The cooking operations are somewhat similar to those described in the soda process, and the washing process takes place after the liquid has been drained off through the screen bottom of the blow pit, shown in Fig. 5, which also shows the digesters used in this process. About three hours is consumed in washing, after which a fine fibrous pulp results. In the soda and sulphate processes previously described elaborate chemical-recovery methods are employed, but in the case of the sulphite process no attempt is made to reclaim the chemicals. However, chemists are investigating the possibility of further utilization. Owing to the fact that the non-fibrous portion of the wood dissolved in cooking represents about one-half of the original wood, about 50 per cent of the raw material for the sulphite process is wasted. The process is relatively expensive, since only about 30 per cent of the original air-dry wood is converted into pulp. The product, however, is of excellent quality and is frequently mixed with the cheaper mechanical pulp in order to give the latter sufficient strength for the manufacture of newsprint.

### PROCESS OF PAPER MAKING

The paper-making process as carried on in the Pacific-Northwest region is practically identical with that in any other section of the country, except in the variations of the refining and sizing operations, and hence will not require treatment here.

Before admitting the pulp to the machine the fiber is made resistant to the ink by the addition of some form of animal or vegetable size or glue, which must be applied to the paper either as

a coating on the sheet or mixed with the pulp in the beating machines. The latter process, known as engine sizing, consists of filling up the interstices of the fiber with a chemical precipitate of finely divided rosin, which when dried on the paper machine makes the paper resistant to moisture. Cheap loading material, such as china clay, kaolin, or calcium sulphate, are added to a moderate extent of from 10 to 15 per cent to close up the pores of the paper. This makes the paper softer and gives the surface a smooth glaze which is especially good for writing and printing. Pigments and colors also are added at this point as required. A process of refinement known as the Jordan process, and consisting of a constant agitation of the pulp to prevent settling of

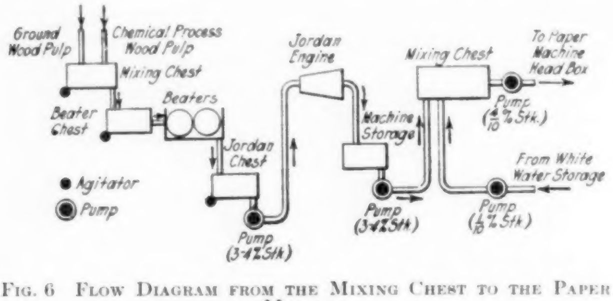


Fig. 6 Flow Diagram from the Mixing Chest to the Paper Machine

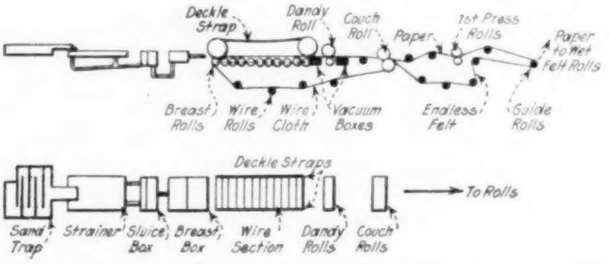


Fig. 7 Diagram of the Wet End of the Fourdrinier Paper Machine

the fibers, precedes admission to the machine storage and mixing chest.

Fig. 6 shows in diagram the flow of materials from the mixing chest to the paper machine. Fig. 7 shows diagrammatically the wet end of the Fourdrinier paper machine and follows the several operations through to the final roll of paper.

## Consumption of Wood Pulp

*Consumption by Process.* There have been described on the preceding pages the four principal methods of manufacture of wood pulp. These can be divided into two principal groups with respect to consumption, the mechanical and the chemical, the latter again being divided into three grades: the soda, the sulphate, and the sulphite. The mechanical, or groundwood, pulp constitutes about 80 per cent of the ingredients of newsprint, of which millions of tons are manufactured annually. It is also used to some extent in the manufacture of other grades of paper and board. Bleached soda pulp is largely an American product and is used most commonly in a variety of both colored and white papers, such as book paper, etc. Sulphite pulp, both bleached and unbleached, is used most extensively throughout the world, due to its variety of grades. When bleached it is the cleanest and the whitest of all pulps, and when mixed with rags gives a very high grade of paper and board. Very good paper is also made from the pure, bleached sulphite pulp, or from a mixture of this and other high grades of wood pulp or reclaimed stock, but such paper is usually inferior in strength and durability to that made from the addition of the first raw materials for paper making—rag stock. Bleached sulphate is used in the manufacture of higher grades of paper.

In the year 1924 the consumption of wood pulp was distributed as shown in Table 6 in the four different processes:

TABLE 6 CONSUMPTION OF WOOD PULP IN 1924

| Process | Cords | Percentage |
|---|---|---|
| Mechanical | 1,643,955 | 28.5 |
| Sulphate | 626,022 | 11.0 |
| Sulphite | 2,691,492 | 46.5 |
| Soda | 806,613 | 14.0 |
| Total | 5,768,082 | 100.0 |

The United States far outranks the other countries of the world in the use of paper, as is shown in Table 7, covering annual consumption in the year 1920.

TABLE 7 PAPER CONSUMPTION OF UNITED STATES IN 1920 AS COMPARED WITH OTHER COUNTRIES

| Country | Pounds per Capita |
|---|---|
| United States | 148 |
| Great Britain | 75 |
| Germany | 45 |
| Scandinavia | 33 |
| Japan | 11 |
| Russia | 5 |

In 1922 there was used in the United States newsprint paper alone at the rate of 45 lb. per capita. Some 74 per cent of the paper used was made of wood, and of this 74 per cent some 56 per cent was purchased. From the year 1916 there has been a decided advance in the importing of pulp wood which is not altogether due to the inability to compete with the foreign countries in the manufacture, but to the decided increase in the demand. In 1922 there was a total of 1,259,000 short tons of wood pulp imported into the United States, largely from Sweden and Canada. This total was divided up into 215,000 tons of groundwood, 714,512 tons of sulphite, and 328,000 tons of sulphate. In the same year the United States only produced some 3,521,600 tons, which means that 26 per cent of the pulp wood available for consumption was imported.

In 1926 the United States imported more than 1,700,000 tons of pulp, 300,000 tons being mechanical and 1,400,000 tons sulphite and sulphate, an increase of 441,000 tons per year in the past four years. These figures are exclusive of the wood imported and manufactured into pulp in this country, which amounted to some 1,500,000 cords. In this same year it is estimated that not over 2,000,000 lb. of paper were made from wood grown in America. Also, 4,300,000 tons of paper were made from reclaimed stock and home-grown wood, as compared to 3,521,000 tons in 1922. The pulp consumption has been increasing from 5 to 7 per cent annually, and of this total quantity of pulp used approximately 22 per cent is from wood grown in the United States.

In Fig. 8 it may be seen that the consumption of pulp has steadily increased since 1922, which was an abnormally low year. It may also be seen that the imports have increased with the consumption, which shows that the home production has not kept pace with the consumption.

*Consumption by Species.* From the statistics compiled for 1924 it is found that the wood consumption by species was as shown in Table 8.

TABLE 8 WOOD CONSUMPTION IN 1924, BY SPECIES

| | Per cent of total consumption |
|---|---|
| Spruce—Domestic | 36.1 |
| Imported | 15.4 |
| Hemlock | 16.7 |
| Yellow Pine | 7.4 |
| Poplar—Domestic | 3.8 |
| Imported | 2.7 |
| Balsam Fir | 5.4 |
| White Fir | 1.6 |
| Larch | 1.3 |

None of the other species formed more than 5 per cent of total.

### Production of Wood Pulp

*In the United States.* Every portion of the United States is engaged in the production of wood pulp to a greater or less degree, the center of production in the past having been in the New England States. In recent years, however, the pulp industry has spread to an unbelievable extent, and has not, as have most industries, moved from one locality en masse to another, but has branched out all over the United States. Table 9 gives a very good idea of the general distribution of the industry, having been compiled for the year of 1924. Since that time the expansion has been on an even greater scale, the principal tendency being towards the Southern States, and in the course of the past year towards the Pacific Coast States.

TABLE 9 PRODUCTION OF WOOD PULP BY QUANTITY AND VALUE, BY STATES

| State | Quantity, Tons of 2000 lb. | Value in dollars Total | Average per ton |
|---|---|---|---|
| United States | 3,723,266 | 186,724,129 | 50.15 |
| Maine | 895,451 | 41,823,676 | 46.71 |
| New York | 755,156 | 33,540,521 | 44.42 |
| Wisconsin | 609,081 | 30,475,682 | 50.04 |
| Pennsylvania | 216,862 | 16,315,962 | 75.24 |
| Washington | 159,539 | 5,265,969 | 33.01 |
| New Hampshire | 151,863 | 11,296,230 | 74.38 |
| Michigan | 145,565 | 8,080,260 | 55.51 |
| Minnesota | 141,165 | 6,236,781 | 44.18 |
| Virginia | 136,105 | 8,620,315 | 63.34 |
| Louisiana | 52,872 | 2,180,553 | 41.24 |
| Vermont | 45,587 | 1,672,485 | 36.39 |

Throughout the United States there is a total of not less than 1680 mills engaged in the pulp and paper industry; of these, 840 are paper mills, 315 are pulp mills, and 525 are pulp-less paper mills.

*In Washington.* At the present time it is difficult to approximate the production of wood pulp in the state of Washington for any definite period of time, as there are announcements every day of the construction of new mills or the expansion of older mills. At the present time a great many of the established lumber companies are investigating the industry with an idea of operating the pulp industry in conjunction with the lumber mills. This is particularly feasible at the present time, due to the fact that the mills have as a rule cut the timber on the lower levels and have moved back to where there is a greater percentage of hemlock in their timber stands. Then, too, the constant inquiries by Eastern capitalists regarding the possibility of locating sites, as well as the floating of new bond or stock issues for new mills, brings the matter of pulp production in the state within the realms of pure guesswork.

### Importation of Wood Pulp

As is shown in Fig. 8 the imports comprise a large part of the total consumption in the United States. This fact is particularly true of the state of Washington, and it is found that 37.7 per cent of the sulphite pulp, which formed 29.2 per cent of the total consumption, was imported; 15.2 per cent of the mechanical, which formed 24.7 per cent of the total, and 44 per cent of the sulphate, which formed 9.6 per cent of the total, also was imported; the balance of the consumption being taken care of within the state. There was practically no exportation of the different pulps. These figures hold true for pulp only, as it has been found that the imports of paper were not so marked. Only 47 per cent of the total consumption of newsprint, which formed 28.8 per cent of the total consumption, was imported, and as in the case of pulp there were practically no exports.

### Exportation of Wood Pulp

There exists a great possibility in the future development of the export trade in Washington. By no means is the education of the Oriental countries to the use of paper a minor one. The paper mills of Japan alone consumed 769,301,726 lb. for nine months of the year 1926, the pulp for all of this being imported, since the Japanese Government has forbidden the cutting of pulp wood for some time to come. The new Occidental Pulp Mills at Edmonds, Wash., have contracted to furnish a Japanese paper mill with 400 tons of pulp per month during the year of 1927, which indicates the beginning of a coming export-trade prospect. There is no locality with a better situation than Washington for supplying this market.

The Department of Commerce states that more than $3,000,000 worth of paper is exported annually to the territories. Alaska consumed paper to the value of $250,000 and Hawaii consumed

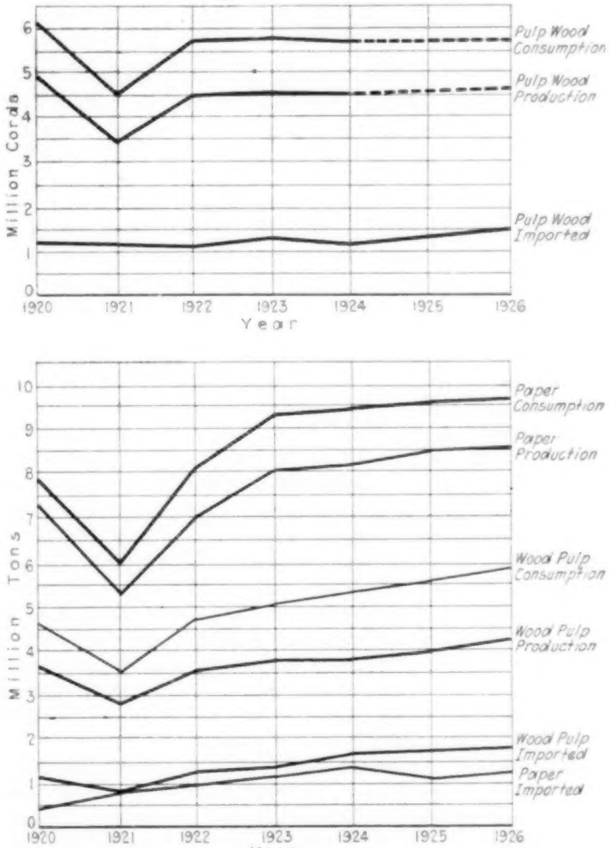


FIG. 8 CONSUMPTION, PRODUCTION, AND IMPORTS OF PAPER, WOOD PULP, AND PULP WOOD IN THE UNITED STATES

from $1,000,000 to $1,500,000 worth, which is more than 50 per cent of the exports to the territories.

As an indication of the possible markets of pulp from this section of the country, it is interesting to note that one steamship company states that there is in excess of 1000 tons of pulp per month loaded for Havana.

The paper markets of the lower half of the Western Hemisphere have been dominated by the German mills, but in view of the distance between Germany and these markets, it seems logical to believe that as soon as production has reached the stage where it can take care of the home market, there are wonderful possibilities in competing with the Germans for these markets.

### The Location and Production of Mills

With one exception the paper mills of Washington are located west of the Cascade Range; this single exception being the mill at Spokane, which finds a market for its product in Texas and Oklahoma. The balance of the mills are located along the coast,

and an incomplete list of the present mills is given in Table 10, together with their location and approximate rated capacity.

TABLE 10 PAPER MILLS IN WASHINGTON—CAPACITY BY SPECIES—TONS

| Location and name | Mech. | Sulphite | Soda | Sulphate |
|---|---|---|---|---|
| Camas—Crown Willamette Paper Co. | 90 | 155 | .. | 100 |
| Lowell—Everett Pulp & Paper Co. | .. | .. | 60 | .. |
| Port Angeles—Wash. Pulp & Paper Co. | 220 | 75 | .. | .. |
| Port Angeles—Paraffine Co. | 30 | 30 | .. | .. |
| Sumner—Paraffine Co. | 35 | .. | .. | .. |
| W. Tacoma—Cascade Paper Co. | 50 | .. | .. | .. |
| Spokane—Inland Empire Co. | 75 | 30 | .. | .. |
| Edmonds—Occidental Pulp Mill | 40 | .. | .. | .. |
| Vancouver—Columbia River P. Co. | | | | |
| Bellingham—San Juan Pulp Mfg. Co. | 45 | .. | .. | .. |
| Bellingham—Pacific Coast Paper Mill | | .. | .. | .. |
| Anacortes—Anacortes Box & Lbr. Co. | 50 | .. | .. | .. |
| Tumwater—Tumwater Paper Mills | 20 | 50 | .. | .. |

Much difficulty was met in securing accurate information as to the mills in operation, but the table contains practically all those of importance at the time of writing.

### Transportation Facilities

*Water Rates.* The Pacific Northwest is particularly fortunate in its transportation facilities. Puget Sound makes an indentation in the coast line, with harbors equal to any in the world. It is accessible at nearly all points to any of the 119 steamship lines that have Seattle as their port of call. The shore line is so characterized that the mills may be built directly on the water front and the products loaded directly on the boats without the costly loading and reloading of short railroad hauls. In the southern part of the state the Columbia River is navigable far into the timbered region, permitting loading direct from the mills, as is the case on Puget Sound. Due to the competition with the railroads the intercoastal service is of the best, and the efforts of the steamship companies operating to the Orient to retain their position in commerce makes this service also very good. Competition between trucking lines, the railroads, and the steamship lines, make the Pacific Coast service all that could be desired. To the East Coast, north of Charlottesville, N. C., for a minimum of 24,000 lb. when compressed to 51 cu. ft. per short ton, there is a rate of 35 cents per hundred pounds. To the Orient, Yokohama, Manila, and Hongkong there exists a rate of six dollars per weight ton, and to Shanghai a rate of six dollars and fifty cents per weight ton.

*Freight Rates.* As is the case with the various steamship lines, the Pacific Northwest receives the benefits resulting from the keen competition among the railroads. There are at present four trans-continental railroads serving this district which have branch lines, or which connect to privately owned lines, covering practically the entire state. This is especially true in the timbered districts, due to the fact that the different lumber companies have constructed railroads into the timber districts, where there was not one already, to transport their logs.

### Cost of Production

No definite figures can be compiled as to the cost of production for the Pacific Northwest with respect to either the pulp or the paper manufacture, as the conditions vary almost from day to day and from locality to locality. Mills are at present in operation ranging in capital invested from $150,000 for a two-grinder pulp mill, to $5,000,000, the latter figure being the estimated cost for a mill now being planned for construction at Bellingham. In comparison with Eastern conditions, it is found that the cost of pulp wood at the mill is less than one-half per cord, and for the immediate future at least, according to some authorities, this price will decrease and not increase. Wage scales are about on a par with the East, although they may be a little higher here. The cost of construction of the plants is decidedly cheaper on the Pacific Coast.

The cost of chemicals is but slightly higher than in the East, and as time goes on and the resources of the West become more developed these prices will be reduced.

Following is given the prevailing market prices for the various pulp products for January, 1927:

| | |
|---|---|
| Foreign— | |
| Ground wood per moist ton | $0.36 to $0.38 |
| Ground wood per dry ton | 0.38 to 0.42 |
| Domestic— | |
| Ground wood per moist ton | 0.30 to 0.33 |
| Imported— | |
| Bleached sulphite | 3.75 to 4.50 |
| Unbleached sulphite | 3.00 to 3.15 |
| Bleached sulphate | 3.75 to 4.00 |
| Prime Kraft pulp | 3.05 to 3.10 |
| Domestic— | |
| Bleached sulphite | 3.65 to 4.75 |
| Unbleached sulphite | 3.25 to 3.75 |
| Prime Kraft pulp | 3.00 to 3.50 |

### General Summary

Of all the great national industries the paper industry receives probably least advertising despite the fact that its products are essential to the industrial life of the nation, and to the moral and educational development of its people. Over 10,000,000 pounds of paper and paper goods were manufactured in the United States during 1926. Even in the state of Washington, according to the latest Federal census, where the pulp and paper industry is in its infancy, it is among the ten leading industries. At present the recognized center of the industry is in the East. There is a great business transition going on at present throughout the United States due to the shifting of the tide of population, to the uncovering of new sources of raw materials, to the location of new routes, and to better methods of transportation. This is particularly true of the pulp industry. According to authorities, reforestation has not been highly successful in the Eastern States, and it is asserted that the Eastern mills have no assurance of an adequate supply of wood for more than five or ten years. The logical solution is to go where the raw materials are found in abundance. Due to the immensity of the industry it cannot be located in any one locality, as is the case with other industries, but there will be a recognized center of trade, and from all appearances that center will be in the Northwest. This is only logical in view of the enormous stands of virgin timber, the decided superiority over other sections in the success of reforestation, and innumerable other factors which govern the development of the industry.

Not alone in the success of reforestation does Nature seem to favor the Northwest. She has provided the necessary raw materials in sufficient quantities, and has supplied an abundant supply of pure water and hydroelectric power to suffice for the entire pulp and paper industry. As the years go by and the methods of transportation advance it will be found that the Northwest is not far removed from the balance of the world, as it was considered a few years ago. It has ideal shipping facilities and some of the best harbors in the world. The Northwest has an established lumber industry which makes the logging problem a secondary one as far as methods, labor supply, etc., are concerned. There exists an ideal climate with small variations in temperature throughout the year, making year-around operations possible in practically all sections of the country, which results not only in the curtailment of loss due to idle machinery, but also those resulting from frequent labor turnover. The pulp and paper industry capitalists have not lost sight of these facts, and at the present time established concerns, as

well as newer ones, are either constructing plants or are investigating sites for possible location.

Manufacturers of mill equipment have been established; mill engineers, operating consultants, etc., have migrated and established offices in this section of the country, as have paper brokers and consumers; all of which shows that in the minds of a great many experts the Northwest is the coming field in the pulp and paper industry.

The Federal Government has adopted a very liberal policy toward the pulp industry with respect to its timber lands, as has the state government. The state has also taken a definite step towards sponsoring a laboratory, similar to the government laboratory at Madison, Wis., which is to be located at the University of Washington with the idea in view of solving the different problems that arise in the pulping of the western woods.

The developments are going on by leaps and bounds; what has been written today on the industry is no longer true for tomorrow; but that does not deter the authors from making this very rough survey of the entire field as it now stands, in the hopes that it may be a condensed summary of the radical changes taking place and a guide to the industry of tomorrow.

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# Change in Moisture Content of Lumber During Rail Shipment

## Results of Some Tests Made on Shipments of Douglas Fir Lumber Shipped by Rail During The Winter Season From the West Coast to Chicago

By G. E. FRENCH,[1] MADISON, WIS.

ENGINEERS are interested in the degree of seasoning at which standard sizes of lumber apply, and frequently also in the possibility of obtaining lumber of some specific moisture content that fits it for a special use without the risk of changes in dimension due to shrinkage and swelling. It is therefore important to know to what extent the moisture content of lumber changes during the long rail hauls that are now a common necessity of lumber marketing.

This paper presents the results of an investigation made to determine whether or not lumber placed aboard cars at the sawmill at a low moisture content will change in moisture content during transit to such a degree as to defeat the purpose of careful seasoning for general or specific uses.

As a preliminary step in the study, representatives of the Forest Products Laboratory and of the Forest Service district products office, Missoula, Mont., early in 1926, determined the change in moisture content of six carloads of lumber shipped from Idaho to the vicinity of Chicago. The late winter and spring season was selected as the time for the tests because this is the period of highest humidity of the year. In the six cars tested containing largely inch-thick flat stock of white fir, western yellow pine, and western white pine, the moisture change of material while in transit was slight except for some material with an average moisture content of 30 per cent that lost about 5 per cent.

In view of the small changes which these shipments showed, the Forest Products Laboratory decided in 1927 to determine not only the change in average moisture content for carloads of lumber but to show in what portion of the load local changes, if any, were taking place. The cooperating company, whose plant is located in western Oregon, was shipping clear grades of Douglas fir kiln-dried to an average of 8 per cent moisture content and common grades of Douglas fir kiln-dried to approximately 20 per cent. Five cars of flat clears were tested, one car of clear quarter-round and crown molding, and one car of common shiplap. Eighteen sample boards were placed in the same relative position in each car. They were protected from any extra-moist boards in the vicinity by being placed between check boards of approximately the same moisture content as the sample. Each sample board was sampled for moisture content and weighed to the nearest hundredth of a pound at the time it was placed in the car. At destination (Chicago) the sample boards were again weighed and moisture-content tests were made. As a check upon these two methods of determining the change in moisture content the total weight of each shipment was determined at the point of origin and destination by weighing the car loaded and empty. The results obtained by all three methods, namely, (1) change in weight of sample boards, (2) change in weight of total shipment, and (3) change determined by moisture-content determinations of the samples at origin

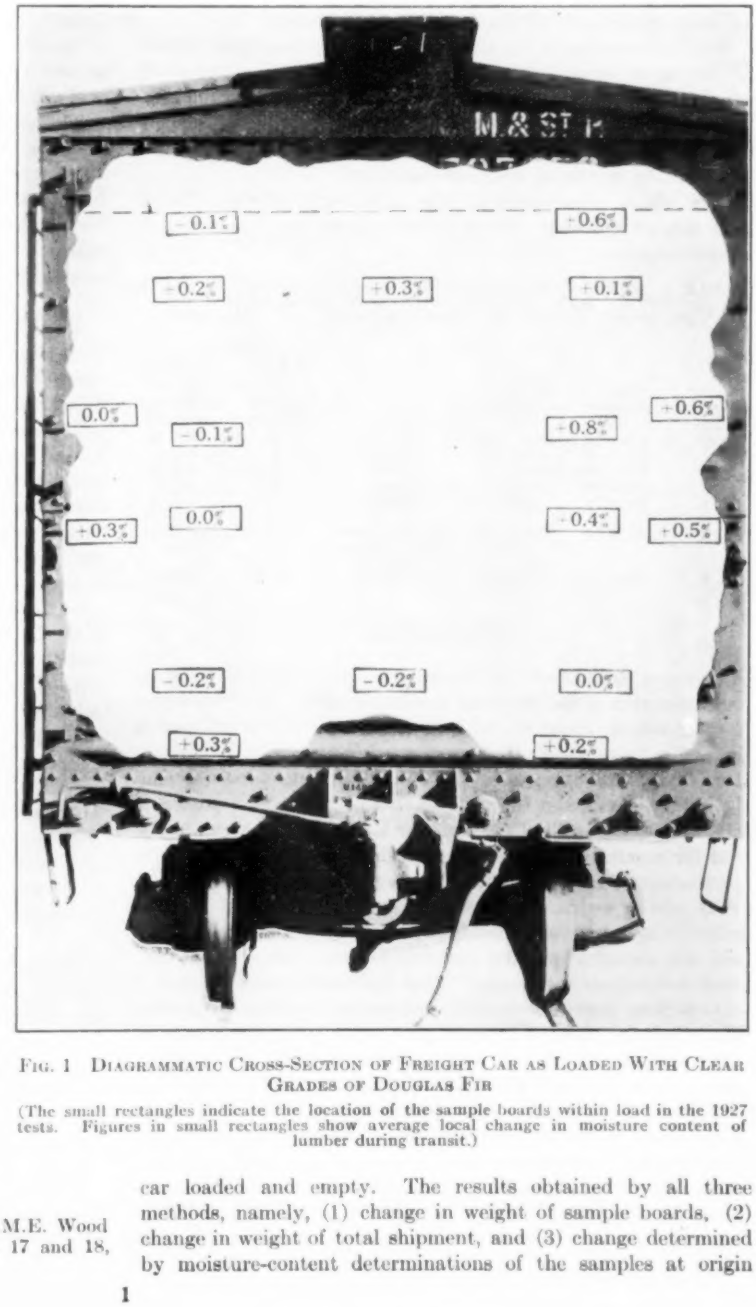


Fig. 1 Diagrammatic Cross-Section of Freight Car as Loaded With Clear Grades of Douglas Fir

(The small rectangles indicate the location of the sample boards within load in the 1927 tests. Figures in small rectangles show average local change in moisture content of lumber during transit.)

[1] U. S. Forest Products Laboratory.

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and destination, were so similar that only those changes shown by the sample-board weights need be considered here.

The data obtained are shown in Table 1 and illustrated graphically in the diagrammatic cross-section of the freight car in Fig. 1. For the five cars of flat clear Douglas fir the average change in moisture content was a 0.2 per cent increase (based on the oven-dry weight of the samples); for the more loosely loaded molding, 0.8 per cent increase; and for the common lumber, a loss of 0.4 per cent. The changes were so small as to fall well within the possible error of moisture determinations. The samples distributed throughout the loads gave no definite indications of local changes. As all of these shipments were made from the West Coast two-thirds of the way across the continent, with only the ordinary precautions used in loading box cars during the wettest period of the year, it is quite reasonable to conclude that during the usual haul in good box cars no appreciable change in moisture content of lumber need be expected.

This information is significant. It means that stock placed in the car in satisfactory condition as to moisture content will reach the unloading point in practically the same condition. If, on the other hand, it is received in bad condition by the consignee, the fault, unless the car is in a poor state of repair, must be with the seasoning methods employed.

The virtual elimination of this "unknown" between shipper and consignee brings the moisture-content problem one step nearer solution.

TABLE 1 CHANGE IN MOISTURE CONTENT OF DOUGLAS FIR SHIPPED BY RAIL DURING THE WINTER SEASON FROM THE WEST COAST TO THE VICINITY OF CHICAGO

| Carload shipment No. | Date shipped, 1927 | Date reached consignee, 1927 | Grade | Average moisture content when loaded, per cent | Change in moisture content in transit, per cent |
|---|---|---|---|---|---|
| 1 | Jan. 25 | Feb. 10 | Clears | 8 | +0.2 |
| 2 | Feb. 4 | Feb. 28 | Clears | 8 | +0.3 |
| 3 | Feb. 10 | Mar. 4 | Clears | 10 | +0.3 |
| 4 | Mar. 18 | April 5 | Clears | 9 | −0.1 |
| 5 | Mar. 25 | April 16 | Clears | 7 | +0.3 |
| Av. | | | | 8 | +0.20 |
| 6 | May 5 | May 25 | Quarter-round and crown molding | 8 | +0.8 |
| 7 | May 6 | May 24 | Common | 21.0 | —0.4 |

## Discussion

ARTHUR KOEHLER.[2] At present the old method of moisture determination is the one most commonly used. In this method a cross-section about $^3/_4$ in. wide is cut out of a board, and is immediately weighed. It is next dried in an oven at a temperature of 212 deg. fahr. until the sample no longer loses weight. It is then considered to be "oven-dried." It is well known to chemists that not all of the moisture is removed by this process, but for practical purposes it is considered absolutely dry. The percentage of moisture is then computed from the two weights. With pitchy woods, like pine and Douglas fir, there is a loss in oils that are also evaporated from the wood; ordinarily, however, this is a negligible quantity and does not affect the moisture content determination seriously. This is a cumbersome method of determining moisture content, and we are working to produce some simpler method. Some promising pieces of apparatus have been developed, but they are not yet ready for commercial use. There is a definite relation between moisture content in wood and the humidity of the atmosphere when at equilibrium, irrespective of the species, but a piece of light wood like poplar will change in moisture content more rapidly than a piece of heavy wood like white oak. Therefore, over a limited period of time, such as is required for shipment, it might be possible for one kind of wood to pick up more moisture than another kind. Moreover, sapwood and heartwood are not influenced equally. Sapwood will take on and give off moisture more rapidly. The size of the piece also has a great deal of influence. A large timber has less surface expanse for its volume than a small piece, therefore less change in moisture content is to be expected, but Table 1 of the paper shows that even a carload of molding, which consists of small dimensions, did not suffer serious change in moisture content during transit.

[2] Forest Products Laboratory, Madison, Wis.

THOMAS D. PERRY.[3] The results of the tests are very interesting, but two very essential points are missed. So far as I know, most furniture men who import lumber in freight cars either want it what they call "well air-dried," or kiln-dried, which means a moisture content of 4 or 5 per cent. If the lumber is air-dried and contains about 15 per cent of moisture, I do not believe lumber in this condition will give off much moisture in transit. The author's test shows that lumber with 21 per cent of moisture lost 0.4 per cent. It is my impression that if the lumber under test had contained 4 or 5 per cent of moisture, the absorption in transit would have been considerably greater and would have led to results which the author seems to have waived aside as possibly negligible. My own experience in testing a number of cars of lumber has been that apparently well-dried lumber will show 2 or 3 per cent of absorption, principally in the boards that are exposed, or near the top of the pile, or near the door. That is not a scientific statement, because of the crude way such tests are made in the trade.

R. K. MERRILL.[4] We experimented two or three years ago with dimension stock. These experiments are all filed away carefully in the permanent file, and have never been written up. When this paper came up, I was reminded of what we did in connection with kiln-dried dimension stock. It might be necessary for us to operate a mill; build a modern dry kiln; dry boards, and cut dimension stock very close to the source of supply, such as is being done by some of the body manufacturers. We wanted to find out whether these kiln-dried dimensioned pieces would pick up any considerable amount of moisture in a trip across the country, so we took several pieces and shipped them in freight cars, along with our finished product, to Los Angeles and to New York City, with instructions to the warehouse men at the other end to enclose these pieces in oiled paper, which we sent along with them. We laid them open in the freight car, without any attempt to cover them up, and, in fact, on top of the pile of material in the car. The pieces were then shipped back, enclosed in the oiled-paper container, and were tested when received. The results showed that the samples had not absorbed in excess of one per cent of moisture, based on the bone-dry weight. We were convinced from that that we could safely ship kiln-dried dimension stock to the seaboard, if necessary, and there assemble it without very much greater deterioration than it would experience in allowing it to stand around in the factory.

PAUL H. BILHUBER.[5] I have made extensive tests as to the gain in weight of lumber due to moisture absorption. Stock for cabinet work that is dried down to 5 and 6 per cent of moisture will gain about 2 per cent of moisture in the shop before it is in the finished article. In summer weather, or wet weather when difficult to keep the windows closed, there is the greatest gain; it averages about 2 per cent. In winter weather the lumber will sometimes stay at dry weight; especially if in a dry part of the

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[4] American Seating Co., Grand Rapids, Mich. Mem. A.S.M.E.

[5] Asst. Factory Manager, Steinway & Sons, Long Island City, N. Y. Assoc-Mem. A.S.M.E.

factory where there are process kilns, or warm boxes, or something of that kind. Five or six years ago we bought Pacific Coast stock for a particular piano part, and specified kiln-dried, 6 per cent stock. To the best of our knowledge the stock was so dried. When received in New York, the shipment time varying from 4 to 8 weeks, we noticed a gain of 2 to 3 per cent in moisture. Shipment was by box car. This is a much greater gain than has been indicated here by either Mr. Merrill or the author.

D. J. McLaughlin.[6] Mr. Perry's remarks are quite interesting to me because of an experience that I had some time ago with the Wood Mosaic Company, in connection with their Victor contract.

The Wood Mosaic Company kiln-dries lumber to 3 per cent moisture content, and it has been found necessary to paper the cars in order that the material could be used without redrying when received.

Experience has shown that different materials pick up from 2 to 3 per cent of moisture between Louisville, Ky., and Camden, N. J. The wood referred to was chestnut, and to my mind this bears out the argument that different kinds of wood pick up different quantities of moisture in transit under equal conditions. The soft wood picks up more than the hard wood.

[6] Yawman & Erbe, Rochester, N. Y.

# The Need of Research on Tropical Woods Before Marketing Them

By ARTHUR KOEHLER,[1] MADISON, WIS.

*After establishing the value of research in woods over cut-and-try methods of determining their properties and values, the author discusses two main lines of research which should be carried on with tropical woods, the determination of the normal properties of the species of wood, and the determination of means of overcoming objectionable qualities that may appear in the species.*

To talk about the need of research on tropical woods before trying to market them on a large scale may seem a bit like overdoing the modern trend toward scientific exactitude, especially when we consider that man had learned to use all the important European and American woods with a considerable degree of efficiency before the word "research" ever was heard outside of learned halls. Ordinary common sense suggests the question, why can we not go ahead and import new species of timber from the tropics and find out what they are good for, just as our forefathers found that hickory is the best wood for handles, cedar one of the best for fence posts, and white oak one of the best for wagon gears, before any scientific tests ever were run on these woods? Scientific common sense answers that we can, but that way of going at it is too slow and costly. How many birch, beech, maple, and other kinds of handles were broken in use before it was discovered that hickory was better? How many spruce and basswood fence posts rotted out in short order before it was realized that they are not so durable as cedar? And how many wagons broke down on the highway on account of having used unsuitable woods in their construction? It is a long story, the development of the use of the right kind of wood for the right purpose, some of it dating back to the dawn of civilization. Even yet the story is not complete, for we can find any number of cases of the wrong kind of wood being used for specific purposes, or of whole industries being guided by prejudices which have no foundation in fact.

Research furnishes data more quickly than cut-and-try methods. There is nothing mysterious or uncanny about research. It is simply systematized investigation. Instead of the so-called practical method (but in reality not highly practical) of trying this and that until a suitable combination is reached by the hit-and-miss method, research takes advantage of all the available information on a subject and then finds new facts to connect with what is already known. It is an interesting side-light on the progress of civilization that two such old and basic industries as farming and lumbering have much less research to their credit in proportion to their extent and age than some of the newer mechanical industries. Necessity, not initiative, is the mother of invention. Nor has the lumberman any brighter prospects ahead immediately, because the road to prosperity has not been paved with research; in fact, in some cases it is not yet known in which direction the road should be laid out.

In addition to furnishing data comparatively quickly, scientific research when properly carried on does away with guesswork and supplies facts. Good research is conducted under controlled conditions by men who are trained to observe carefully, to see small differences, and to make unbiased reports, whereas rule-of-thumb data are developed under varying conditions, often by untrained observers, and as a result usually lead to conflicting practice.

Finally, research is a capital investment. A piece of research properly carried out need never be repeated; it is not a recurring expense. Generation after generation can use it and build an addition to it without in any way impairing the value of the original structure. Knowledge once gained is good for all time.

## Main Lines of Tropical-Wood Research

In the study of tropical woods there are two lines of research which should be carried on:

1 The determination of the normal properties of the species of wood

2 The determination of means of overcoming objectionable qualities that may appear in the species.

## Determination of Normal Properties

Wood has more than a score of properties that are important in its utilization, among which are the following: weight, strength as a beam, toughness, stiffness, hardness, resistance to wear, stability, plasticity, durability, workability, nail- and screw-holding power, gluing characteristics, finishing characteristics, and heat insulating. For some uses a single one of these properties, as durability, may be of major importance, while for other uses a combination of several properties may be essential. Just a slight difference in properties may throw the balance in favor of one or another wood in specific cases. It is therefore essential to know what the properties of a species are so that a proper evaluation can be made of each species and each kind of wood can be used for purposes for which it is best suited.

Research on tropical woods is all the more important because practically nothing is known about most of them except what can be learned from natives and the uses to which they have put them, facts which often have little bearing on industrial uses in this country.

Whatever tests are made on tropical woods should be so performed as to yield direct comparisons between the new species and those with which we already are familiar. I mean tests should be conducted under the same conditions as to size of specimens, moisture content, etc., as govern the accepted tests of our American species. This does not mean that the tests must necessarily be made at the Forest Products Laboratory. Other institutions properly qualified and equipped could make comparable tests.

The comprehensive tests already made by the Forest Products Laboratory and others on native woods have paved the way for research on tropical timbers by showing which kinds of tests are the more important and how they should be made. It is out of the question at present to make as thorough tests on foreign species of wood as have been made on the important native species, and perhaps our institutions should never attempt anything quite so elaborate.

The following are some of the more important things that should be found out concerning the normal properties of tropical woods before importing them: (1) Means of recognizing each kind; (2) specific gravity of individual species, since it not only

[1] In charge, Office of Wood Technology, Forest Products Laboratory.

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indicates the weight to be taken care of in shipping and handling, but it is also an indication of some of the other physical properties, such as strength and hardness; (3) actual strength values, by test, where the wood might be used for structural purposes; (4) ability of the wood to stay in place, which requires a knowledge of its tendency to shrink, swell, warp, and cup; (5) how the wood seasons in the open air and in kilns; (6) how it cuts into veneer; (7) how to glue it properly; (8) how easily it works under tools; and (9) what difficulties, if any, it presents in finishing.

How effectively a wood resists decay and insect and marine-borer attack and how it can best be treated with preservatives are matters of importance mainly for wood which is to be stored or used in damp places or where certain kinds of insects or other pests particularly abound. This question of durability applies especially to railroad ties, piling, and structural timbers, but there are many industrial uses in which it is of minor importance. For this reason, and because of the long time required to obtain full information on durability, tests of this nature could be omitted on tropical woods to be stored and used under conditions favoring immunity from destructive organisms.

### Overcoming Objectionable Qualities

The other line of research, namely overcoming handicaps, is a relatively new one with respect to lumber. It has been done with some species, notably red gum, which years ago had no stumpage value on account of its strong tendency to warp, but now is used in high-grade furniture because methods of drying have been developed which reduce warping to an almost negligible minimum. The tendency of many species to rot quickly also has been overcome by preservative treatments. There are many species, however, not only tropical timbers but among our native species, that have objectionable features not as yet overcome which now give them a relatively low value.

This is a tremendously important field. If the properties of a wood can be modified to meet certain needs, then its serviceability and value are at once greatly increased.

And why should it be not possible to modify the properties of wood? The properties of a multitude of other materials have been modified. The properties of cotton, for example, are changed considerably by mercerizing; the quality of steel is greatly modified by the admixture of small quantities of certain rarer metals as vanadium or tungsten; gasoline is given anti-knocking properties by the addition of tetraethyl lead; animal glue is made water-resistant by the addition of paraformaldehyde; certain foods can be given anti-rachitic properties by treatment with ultra-violet rays; salt is treated to make it less hygroscopic so that it "pours when it rains;" and the texture of Swiss cheese is controlled by inoculation of the curds with certain bacteria. Who knows what the limitations of wood are? Nobody knows because no one has determined its limits of usefulness if correctly handled.

Seasoning and application of preservatives are the only two processes applied on a large scale which change the properties of wood and make it better suited for certain uses.

One of the immediate needs in improving the quality of certain species is overcoming the raising of the grain on the surface after sanding. This one feature has given a black eye to numerous woods otherwise highly desirable.

A reduction in the shrinking and swelling of wood under normal moisture changes would overcome one of the chief handicaps of lumber for construction and manufacturing purposes. If the shrinking and swelling of wood could be reduced one-half by some kind of treatment, a new era would dawn in the use of wood.

Another need is some method of hardening the surface of wood by impregnation or otherwise so that the softer woods can be used for parts of furniture, musical instruments, interior finish, flooring, etc., in which a high degree of strength is not essential but a certain amount of resistance to wear and indentation is necessary.

Making the use of fire-resistant processes for wood more practical would overcome some of the objections to all kinds of wood.

A procedure very beneficial to producer and consumer of lumber alike would be to classify those species of wood which have a wide range in density into two or three density groups, each group suitable for certain uses.

Some species of wood are highly variable, so that it is necessary to know the range in properties and to make allowances in use accordingly. Mahogany is a good example. Some of it is so hard and heavy that it almost sinks in water when dry; other pieces are so soft that they are not suitable for exposed parts of furniture. By knowing their range in properties it is possible to classify such species of wood into groups suitable for different purposes. The heaviest groups might be best for substantial parts of furniture, the lightest might be used to best advantage for core stock, and an intermediate group might be just the thing for room interiors or parts of furniture not subjected to severe stress. This idea of grading lumber for intrinsic properties in addition to visible defects is a new one in industry, although grain, cotton, tobacco, and other products have been graded that way for some time. If species of wood could be sub-classified into groups in a practical way, the producer could sell each group to those interests requiring the properties represented by the group, in that way obtaining a more satisfactory market, and the consumer could get the particular quality that he desired.

These are only a few of the things that could be done toward obviating objections to foreign species of lumber—and to some of our native species as well.

One of the hindrances to the exploitation of tropical forests at present is that woods of many different species occur in a stand, of which only a few are of possible use and the others must be left, thereby increasing the cost of logging. By knowing the properties of all the common kinds in a particular region or country, the best uses for them could be ascertained, and by knowing how to overcome objectionable qualities, additional uses could be found. With such information more complete logging could be carried on in any given forest area of the tropics.

## Discussion

H. S. Fleming.[2] I am very much in accord with the author's proposal to have research work undertaken in respect to tropical woods and their treatment, and more especially in the matter of the treatment and handling at or near their point or origin with a view to determining means of avoiding the loss through checks and splitting which occur after the woods leave the humid atmosphere of the tropics and begin to dry out.

I especially commend the point that woods of many different species occur in a stand, of which only a few now have any commercial use, thus increasing the cost of logging, and that this situation might be greatly improved if the properties were known of the woods which have no commercial value. In my experience in the Amazon Basin, I found as many as 60 species of wood in one acre, and it is rare to find any considerable number of one species in a stand or within a reasonable distance of another of the same species.

H. P. Brown.[3] The utilization of the various tropical woods which are coming into this country, or which will be introduced in

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[3] Professor of Wood Technology, N. Y. State College of Forestry, Syracuse University, Syracuse, N. Y.

the future, hinges in no small degree upon a proper understanding of their technical properties. Fortunately, a routine schedule of research sufficient to determine the feasibility of the utilization of a given kind of wood for a specific purpose is already well established for our domestic timbers, and the author's proposal to pursue this same plan in research upon tropical woods is well taken. Standardization of research data, especially those of timber testing, is absolutely essential, even though these are at best only relative in their application. Not only is standardization desirable in the United States, but also between research centers in various countries, a fact which is already accepted in England and India. I believe that we who are interested in research upon wood can state, with all due modesty, that we are prepared to conduct such research on tropical woods in a manner satisfactory to the trade.

The successful introduction of tropical woods into this country, in my opinion, is less concerned with research, necessary as it is to determine their proper use, once here, than with the problem of their delivery into this country in sufficient quantity and of sufficient quality (to grade) to insure their general utilization. In other words, acceptance or rejection depends more on the quantity and the condition of the supply than upon the technical properties. This is rather a bold statement, but since wood lends itself to so many uses, surely some good can be found in almost any tropical timber unless prevented by price, quality, or the volume of the supply.

A few of the obstacles which the importer of tropical woods must surmount if he is to meet with success in his venture are discussed below.

1 *Prevention of Fungal Decay, Insect Infestation, and Marine-Borer Work.* The rapidity of fungal decay of wood in tropical-rain forests and at certain seasons of the year in monsoon (periodic rain) forests is always a source of surprise to one whose experience in this respect is restricted to the temperate zones. From my observations upon tropical woods I have been led to infer that it is practically impossible to ship some of the lighter, more perishable timbers any distance without serious depreciation from fungi, even though the sapwood is removed. Loss from this source could be materially lessened were proper measures employed in the jungle, but the importer must remember that he is dealing largely with illiterate, crude labor, and often with the silly superstitions of ignorant jungle folk. Moreover, in the tropics the boring insect is always to be found, and poor harbor facilities add to the difficulties, necessitating delays which encourage marine borers. Importers, therefore, must be prepared for disappointments.

2 *Lack of Sufficient Supply.* With the exception of the dipterocarps, which are restricted to the Indo-Malayan region, I know of no hardwoods which are sufficiently gregarious to form well-nigh pure stands. The problem of successful exploitation is therefore the harder to solve because of the many varieties of trees that grow on relatively small areas, as the author has already pointed out. The lack of winter snows which facilitate logging, of rivers to float out logs, and the fact that the logs of many species will not float, even after prolonged seasoning in the jungle, with its concomitant decay infestation, make lumbering the more difficult.

In many cases the absence of water transportation necessitates land conveyance, often over extremely rough topography, through dense jungle vegetation, and in regions where the tsetse fly prohibits the use of beasts of burden. Furthermore, the ignorance and conservatism of the workmen and the cost of introduction militate against mechanical carriers. In consequence the operator is often restricted to the use of man power to remove logs from the jungle—at best a slow and expensive process.

3 *The Lack of Trade Names.* Mr. Alexander Howard, one of the best-known tropical timber importers of Great Britain, has said that the name under which the wood is placed on the market is one of the most important factors which govern its successful marketing. Man is by nature conservative and loath to try anything new; consequently in order to introduce a new timber, the importer must anticipate a considerable outlay in advertising before his sales will justify operation on a large scale.

4 *Delay in Supply.* There is a lack of firms in the tropics, especially in the Far East, who carry stocks of timber other than of a few well-known species, such as teak, rosewood, etc., that is, woods with an already established world-wide reputation. If an order is placed for lesser-known woods, the reply that usually comes back is that the lumber can be supplied the next working "dry" season, generally six to eight months ahead.

5 *Insistence on the Use of American Grading Rules in Purchasing Tropical Woods.* Firms in the tropics with timber for sale feel that they cannot make the grade. In some countries they have their own grading rules; in others they have rules of but the crudest sort. In many cases the importer must cut the cloth to the subject; he must coin his own rules.

6 *Overestimation of the Timber Supplies of the Tropics.* The term "jungle" does not imply merchantable stands. There are thousands of square miles of tropical forests that cannot be logged at a profit under present conditions. In certain places excellent stands occur, but they are the exception rather than the rule. Weed trees of all shapes and varieties abound, and these reduce the general average of quality and increase the expense of production.

In conclusion, I hope I have not painted the picture too black. I believe in the utilization of tropical woods. Through research we technologists can find and devise uses for tropical timbers, but in my opinion that is the lesser problem in their successful introduction. Success or failure depends not upon finding uses for them once we import them into the country, but in getting them here sound, in sufficient quantity, and of reasonably standard grade and price for commercial purposes.

D. M. Matthews.[4] The waning supply of first-grade native hardwood, with the consequent increase of price, directs more attention every year to the search for substitutes; and substitutes other than wood, at greater prices than wood, and sometimes with less satisfaction in use, are being very generally adopted. It is not willingly that wood users are thus turning to other materials, but only because they can no longer obtain specific wood material in the grades, dimensions, and quantity that they require in their particular industry. Quantity is a very important consideration. Often a user might be willing to accept a wood which he did not consider quite the equal of the material he had been using previously, if he could only be certain of a steady supply of this wood in the quantities which he requires annually.

If the substitution of other materials for wood is to be checked, and if the wood-using industries are to continue their development along the lines for which they are organized, new sources of supply for hardwood will have to be tapped. The only undeveloped source of supply lies in the tropics and, with the exception of such generally used woods as mahogany, teak, and other rare cabinet woods, the timber species which make up the bulk of these tropical forests have only been abortively marketed in temperate regions and less in the United States than elsewhere. We are now in the "cut-and-try," "rule-of-thumb" period with regard to them. Research along the lines suggested by the author is the only way in which we are going to reduce the period of hit-or-miss experimentation so that the tropical-wood resource can be made available in time to take up the slack between the

[4] Professor of Forest Management, School of Forestry and Conservation, Uni rsity of Michigan, Ann Arbor, Mich.

exhaustion of our present native supply and such time as we may be able to grow sufficient to supply at least a portion of our current requirements.

General research to determine the normal properties of any new wood is, as the author points out, a prime requisite, but I am especially interested in the second line of research he mentions, namely, "the determination of means of overcoming objectionable qualities that may appear in any species." The wood-using industry of the United States is, in this day and age, more specialized than ever before and than anywhere else in the world. We use a minimum of labor and a maximum of machinery, and speed is the "essence of the contract" all along the line. This specialization calls for very specific qualities in the woods which we put into use, and slight variations from these specific, standard qualities often cause the rejection of a wood for a specific purpose. Abroad new woods come into use more easily than they do here. In other countries users are willing and able to modify their methods to meet the species. We are generally unwilling to do this, and the suggestion that research may help us to modify the wood to meet our methods is a welcome one. There is a wealth of valuable prime-grade hardwood in the forests to the south of us, but it is unlikely that we shall find many woods, in quantity, which will exactly meet the specifications of woods which are in general use here. Many will be close to native woods in general use, may have qualities which are superior to this characteristic of the native wood, but be turned down because some minor point differs from the native wood in use. I had a very concrete and vexatious example of a case of this sort when exporting timber from Borneo to Australia. We have in Borneo a timber called "kruin," one of the larger dipterocarps, known as "apitong" in the Philippines. We considered it a very fine flooring material and, as we manufactured by hand there, we had no difficulty in working it. We sent samples to Australia. Our friends there were very much taken with the wood, considered it superior to any of the floorings they were getting from elsewhere at the price, and placed an order for several hundred thousand feet of blank flooring stock, intending to tongue, groove, and plane it there so as to avoid duty on finished wood which the Australian tariff imposes. The wood contains a very considerable amount of oleo-resin which, unless the material is very thoroughly dried, will appear on the surface of planed stock for a time. With our slow methods of manufacture this never bothered us.

The Australians proceeded to put our stock through very high-speed planers and matchers which they had been using for Douglas fir. They could not handle it. It dulled the knives; they chattered and produced a rough surface, and the temporary stain of the resin appeared on the planed surface. As a result they refused to accept the shipments. The distance was too great for it to be shipped back, and a 50,000-dollar arbitration case arose which threatened to go to the courts with no one knows what additional expense. We were four years in getting the matter settled, and the firm I was with lost the Australian market. We have since found out that adequate steam kiln-drying removes this objection entirely. Had we known that at the time, we should have saved many thousands of dollars, and a steady trade in the timber would have continued between Borneo and Australia. This is a practical example of how research along this line, as proposed by the author, is going to permit specialized methods and machines to take new woods and put them into use.

Another point in the paper which seems to me of great importance is the proposal to classify tropical species into groups suitable for different purposes. This is a step in the right direction, whereas producers of tropical timber have been too long moving in the opposite direction. The redwood produced by various species of "shorea" in the Philippines, Borneo, Dutch East Indies, and Federated Malay States is marketed in the East under a host of local names, and elsewhere as Philippine mahogany, Borneo mahogany, Borneo cedar, Pacific maple, etc. This is not only unscientific but it is bad business practice. There are enough different woods in the tropics without multiplying them, and yet one firm that I know of has been adding trade names in the hope that they will get all the business in a certain wood to themselves, although the same wood was produced in all the countries mentioned above. This was a very short-sighted policy as the markets where they were placing their product could have taken much more of the wood than they could produce, and the development of a general market was retarded. As the author suggests, we need to group woods of different names but of similar qualities so that quantity production is possible. This will reduce the costs of production and assure steadier supplies to the consumer. However, such grouping must be scientific and based on adequate data as to the characteristics of each species. Such classification should be based on sound research—it cannot be left to the producers themselves, for they have already shown a tendency to move in the opposite direction.

So much for the research into the qualities of the woods themselves. The author has shown that it is a very necessary prerequisite to successful marketing. I would only like to add that research, or exploration if you like to call it so, of the sources of supply of the tropics is an equally needed piece of work, and the information so gathered should accompany the publication of the results of the research on the qualities of the woods themselves. When I was conservator of forests in Borneo I was anxious to have some authoritative data prepared as to the strengths and general qualities of our more important timber species, and I had this work done at the University of Hongkong. When I received the data I handed them over to the lumber companies. They apparently sent out small samples of the various species to all of their agents and customers with labels attached quoting all the more favorable data with regard to each species, but without stating what sizes or quantities could be supplied. Later on I became manager of the largest lumber company in Borneo, and I was more than once embarrassed by firm orders for quantities and sizes of various species which were entirely out of the power of my company either to produce or deliver. I remember one order for 20 spars of Borneo ironwood to measure 96 in. in circumference at the center and 110 ft. in length. As the species rarely has a clear length of over 30 ft. and a diameter of over 24 in., I had to regretfully decline the order. Moreover, as the wood weighs about 90 lb. per cu. ft., the spars would have weighed about 20 tons each if we could have produced them—I don't know how we would have shipped them.

Therefore in our efforts to bring the useful timbers of the tropics into use in this country we must be equipped with a knowledge of the sources of supply and concentrate research on species which can be produced in sizes that will meet market demands and in quantities which will enable industry to standardize with them in use.

The examination of the sources of supply in the tropics should not stop with the mere determination of what species were present in abundance. The accessibility of the larger timber supplies, both as regards transportation to the consuming centers in this country and with respect to extraction costs of the timber in the forests themselves, should be determined and determined in detail, at least for a few strategic points. Utilization plans for a few tracts of a couple of hundred thousand acres each, showing what it would cost to log, mill, and put the finished product down f.a.s. at regular points of call for steamers plying between Central and South America and the United States, are needed so that we may know what species can be produced in quantity and at a cost which will permit industry in the United States to plan for their continued use. In other words, I feel that research into the

specific qualities of tropical timbers and the determination of how they can best put into use in this country should be backed up by information as to probable available supply, dimensions in which the supply can be delivered, and costs. Without this information research cannot concentrate on the important problems, and we need it concentrated on the species that we are going to be able to get in quantity at reasonable costs.

T. H. Gill.[5] The following comment and suggested program is the result of a recent conference with Samuel J. Record, Professor of Forest Products in Yale University.

It seemed to both of us that although there can be no question as to the desirability of more or less elaborate tests on various tropical species, there is strong reason to doubt that such tests will be undertaken in the immediate future. It seemed, too, there might be a place for an interim program which would not only expedite some more elaborate program but which would recommend itself because it could be begun immediately and with relatively small funds.

This program which we thought of as an interim program is by no means intended as a substitute for complete tests that may ultimately be needed. It is rather a suggested means for obtaining immediate results and answering some of the questions regarding the practical possibilities of certain tropical species.

The interim program proposes the formation of a committee with the following three functions:

1 Decide on the species to be tested and the nature of the tests
2 Arrange for the tests with woodworking plants or other agencies
3 Acquire information on the availability, abundance, and local uses of each species.

The working out of this plan would be somewhat as follows: The committee will seek the cooperation of woodworking plants willing to take one or two selected species and give them such practical tests as in the routine of their work they are best fitted to give them. Preferably parallel tests should be made by sending specimens of one species to two or more plants. After an examination of the species the committee will decide to which plants they should be sent and the nature of the tests. It will also be responsible for correlating the results.

If in the light of these practical tests it seems desirable to make further tests for certain species, the work could be modeled on the procedure of the Imperial Institute of London. Tests there are made for sawing, planing, boring, nailing and screwing, gluing, and polishing. Mechanical tests include static bending, compression, shearing, cleavage, tension perpendicular to the grain, hardness, specific gravity, moisture, and weight per cubic foot. These tests are sufficient for nine-tenths of the species and involve no great cost. Of course the important thing is for the industry itself to decide on a wood; and in order to learn the fitness of a wood for specific purposes, the wood should be tried out for those purposes.

In addition to the tests, information regarding the occurrence and local uses of the various species could be obtained from field workers in the tropics. I myself hope to collect within the next three years a deal of data on the range, availability, and uses of the more important species throughout the American tropics.

The above plan would seem to combine the advantages of an immediate start and an adaptability to investigation on any scale that funds may dictate. If very little money is available a start could still be made by experimenting first with species now offered for sale but not yet established on the United States market. The promoters of these would undoubtedly provide specimens for testing purposes. Later the tests could be extended to other woods. British Guiana has recently reorganized its forestry department and is making a survey of available timber areas with a view to getting all information concerning her little-known but potentially important woods. The forester's report for 1926 indicates that they would be willing to supply material for testing.

The program means a definite start toward answering some of the questions that must be answered before the industry will accept new woods—it provides a way of establishing satisfactory species to take the place of those that because of their scarcity are now becoming costly, difficult to obtain, and open to the increasing inroads of wood substitutes.

Willard Winslow.[6] It seems to me, from the point of view of a tropical lumberman, that the value of scientific research in connection with tropical woods is a secondary consideration.

The natives using these woods have long ago worked out, from experience, the standing of tropical woods, as to durability, workability, and the other facts that the author states are important. I should put the factors necessary for the successful use of tropical woods in the following order:

1 Whether the stand of timber is large and uniform enough to make lumbering practicable and not too expensive
2 Whether the woods imported can successfully compete with woods now in use, even allowing for a steady advance in price
3 The climate, freedom from diseases, stability of government, and labor supply
4 Existing or probable means of transportation
5 Scientific research in these woods, as to their suitability for special purposes, after a possible market is established and the other difficulties overcome.

In Manila, Hongkong, Shanghai, and Yokohama the native workmen are satisfied to get hold of small quantities of valuable hardwoods in the log. These woods are sawn and manufactured by hand, and it is not necessary to duplicate a wood to introduce it.

To interest capital to manufacture or log a tropical wood, it must be shown that there is a sufficient accessible volume of several good woods and a large and continuing supply. Also, all the other favorable features which I have mentioned must exist. The absence of any one of these factors would preclude any considerable investment.

To spend the time and money required for scientific research as to the value of tropical woods is a waste of time and money if these woods cannot be obtained in commercial quantities and a steady supply. Any experienced tropical lumberman can tell at once whether the necessary factors are present and whether the wood is suitable to substitute for our vanishing domestic woods.

For example, there is a wood in the Philippines that appears to be a substitute for lignum-vitae, but tests of this wood for tail blocks in ships prove that it is not, as it lacks the oil contained in lignum-vitae. There are several tropical woods that appear to be a substitute for dogwood for shuttles, but tests show that they lack the grain of dogwood and "check." Many substitutes have been tried for pencil cedar, but each one is lacking in some special quality.

The author speaks of "scientific research showing that mahogany was useful for various purposes." The foreman of any factory can tell in a day whether a mahogany is suitable for his work, even if he has never seen it before. The log importers in London and Liverpool can not only tell at a glance what the

[5] Forester for the Tropical Plant Research Foundation, Washington, D. C.

[6] Indiana Quartered Oak Co., Long Island City, N. Y.

wood in question is, but can even tell with certainty from what particular ports of the world the logs came.

The author speaks of scientists sub-classifying mahogany, so that the producer could sell "each group to the proper interests." This is the a-b-c of the mahogany business, and for the past 25 years mahogany has been sorted for special work, and even manufactured to suit special needs.

It is not a generally known fact that the wood of the same tree varies, as well as the wood from different trees of the same species. This selection of wood has been carried to a fine art in the manufacture of high-grade pianos. For example, in the manufacture of the best-known grand piano, spruce was selected with not less than thirteen grains to the inch, as it has been found that slow-growing wood has the most resonance. The maple also used in the case is selected on account of its resonance. The white pine for keys is selected three times, to insure the key's remaining perfectly true. In the manufacture of fast motor boats, where the reduction in weight of the boat is a matter of pounds without sacrificing strength, experience has determined the special mahogany required for each part.

I mention these facts at the risk of redundance to show that scientific research cannot be of any aid as against years of experience. Our forefathers knew perfectly well that a cedar post lasts longer than spruce, but they used spruce when they could not get cedar and not because they did not know better.

The Philippine Malay used Philippine mahogany 350 years ago for planking boats, because he had found that it was the most suitable wood he had. My somewhat extended experience with boats in different tropical countries has led me to the conclusion that the native has found out what is the best available wood for his purpose invariably, and the man who uses the wood knows better than any one else its qualities and defects.

During the past 40 years I have exported large quantities of white pine to ports of the West Indies and South America, where mahogany was used for railroad ties, fences, and hog pens, and where forests of much better woods for their purpose grew all around them. The reason for this is that there were and are no sawmill facilities or transportation to make these forests available in any volume.

Probably the greatest available hardwood forests in the world today are in the Philippine Islands, and yet there are some 26 abandoned sawmills scattered among the Islands. The reason for this is health conditions, lack of labor, capital, transportation, or local markets for the low grades. Ask the investors who were stung!

At the present time foreign corporations cannot compete with local Chinese loggers and lumber yards when it comes to transporting and manufacturing a great number of scattered but valuable and handsome hardwoods. These bring a higher price in their local markets than the most valuable foreign woods imported into the United States.

After overcoming the many difficulties in obtaining a valuable tropical wood in commercial quantities, and establishing a market, we might then avail ourselves of the services of the Madison Laboratories in assisting us to confirm what experience has worked out, especially where the wood is to be used for a very special purpose. If experience proves a wood satisfactory, its botanical status is of no interest to any one but the dendrologist and the nurseryman.

G. P. Ahern.[7] The author brings out clearly the need for systematized investigation in the search for suitable tropical woods to meet our needs. We all know how difficult it is to market a new wood. A wood may have very desirable properties and the price may be satisfactory, but there will be a lack of interest if there is no real guarantee that adequate supplies of such wood can be maintained over a period of years. Scientific research can tell the story of stand and distribution of promising tree species. But preceding the search for suitable foreign woods must come an analysis of wood needs to show:

(a) The specific properties requisite to the various industries
(b) The quantities required by each industry and the extent to which native species will fail of meeting requirements
(c) Range of prices within which new material must be supplied
(d) Definition of qualities which new species must present to meet the requirements of various industries.

With that information, which is now being prepared, we shall seek woods that must meet requirements.

The Main Research Committee of the A.S.M.E. very wisely suggested at the beginning of this project a year ago that as a first step it would be necessary to prepare a bibliography of tropical woods, thereby making available the world's literature on this subject. The first edition of such a bibliography was prepared and several hundred copies issued late in 1926 to persons and organizations interested, including wood experts in some 36 foreign countries.

With each copy was sent a letter explaining the project and requesting cooperation in the preparation of a more complete second edition. A very general and helpful response indicated keen interest and gratification that such data would be collected for the benefit of all. These wood experts have furnished many useful data which will make the second edition, soon to be published, more complete than the first. In addition, the cooperation of these experts now assured will be most helpful following the coming field investigations, when promising tropical-wood specimens are furnished the laboratories and factories for testing purposes. All available information concerning the properties of a wood will be very helpful to the laboratory man or the factory superintendent.

Our Philippine experience will be helpful in this project. Many of the difficulties in the present situation were present in the Philippines 25 years ago, when United States woods were transported 6000 miles across the Pacific to supply the construction needs of the Islands. Field investigations developed the fact that in the 60,000 square miles of Philippine forest, some 20 of the 3000 tree species found there constituted 80 per cent of the stand. That figure holds good to this day. A majority of the 20 abundant species were considered unsuitable to market needs, and some of them could not be sold at any price. A government laboratory and a government workshop developed desirable properties in these abundant but unpopular woods which today find favor in the markets of some fifteen foreign countries.

It requires cooperation in support of a properly equipped organization to make the preliminary investigations as to sources of supply and to conduct researches necessary before new species of wood can be brought into use where they are required and in the quantities demanded.

Great national or world needs of this character are often neglected by governments and industrial organizations until some pioneer with vision blazes the way. Thanks to the Charles Lathrop Pack Forestry Trust, a fund has been provided for a three-year program of tropical-forest research. This trust fund has for its general object the advancement of forestry in the United States, but the Trust recognizes that the timber-producing capacities of the tropics are both a domestic and a world problem. The Tropical Plant Research Foundation of Washington, D. C., has foreseen the necessity of such work, and is prepared to undertake it.

A fact-finding expedition financed by this Trust Fund will be

[7] Tropical Plant Research Foundation, Washington, D. C.

sent by the Foundation to tropical America early in November, under the leadership of Forester Tom Gill. The forests of the Caribbean region will receive attention during the first year. Eventually the expedition will visit all tropical American countries whose forests are of commercial significance. The field of investigation will furnish information concerning:

(a) The location of accessible bodies of timber
(b) The quantities and sizes and distribution of various important species
(c) How these species are being used at present
(d) Primary costs of extraction and milling and approximate costs at which logs or lumber can be laid down at American ports.

The present program of this Foundation survey provides for securing information on tropical woods but not as yet for collecting logs for testing nor for making scientific tests and factory trials of the woods in this country.

It is hoped, however, that additional cooperation may still be secured to defray the cost of securing timber samples, transporting them to the United States, and testing them at the Madison Laboratory or in other institutions.

The following points concerning these woods require attention:

(a) Their definite structure and identification
(b) Their general mechanical properties, strength, durability, workability, seasoning possibilities, finishing, and possibilities of overcoming objectionable qualities
(c) The correlation of their determined properties with uses in the United States
(d) Factory demonstration tests supplementing laboratory investigations.

The story of the local uses of tropical woods, especially of the abundant woods, will not necessarily have a bearing on our industrial uses, but will serve as a hint in conducting tests. Elaborate laboratory tests will not be feasible, due to lack of funds for that purpose, but sufficient information will be made available in advance of tests so as to point the way toward the most promising and most desirable uses of each wood tested, thus saving more or less time and effort. The woods that have stood long-time tests in the tropics in the manufacture of spokes and rims, wagon poles, tool handles, railroad ties, musical instruments, etc., are worthy of study, especially if these woods occur in quantity.

Carelessness in logging and delays and neglect in handling logs exposed to tropical sun and rain account for unfavorable reports as to useful properties. A very different story may be told of such woods when not so handicapped but collected and cared for properly, botanically determined, and definite information gathered concerning stand and distribution, as well as possibilities of extraction and shipment.

The experiences in the past arising from disputed nomenclature of tropical woods coming into our markets (the Philippine mahogany case a recent example) should be a warning of other disputes likely to arise as tropical-forest exploitation expands. As new tropical woods come into the market, some efforts should be made by wood technologists toward standardizing methods of their analysis and description, and with importers, wood users, and others interested arrive at agreement on some scheme for classification.

It is quite possible that logs can be laid down in quantities at attractive prices and manufactured in our hardwood mills without disturbing the hardwood market. A number of hardwood mill companies of the Gulf States are becoming more and more interested in this tropical field; some are looking into the possibilities of securing forest tracts; others are making arrangements for shipments of logs. This development will tend to remove one of the most serious phases of the opposition to imported hardwoods just mentioned. In any event this entire movement toward the development of tropical forest resources will move slowly, and at a rate dependent largely on market demands. The many handicaps in the road will take years to remove. In the meantime research will provide accurate information to meet the needs as they arise.

D. H. Allen.[8] A necessary preliminary to tropical research would seem to be the preparation of a list of domestic woods for which substitute species are needed either by reason of the high price of the domestic wood or because of its inferior grade.

Much wasted effort and expense could be saved if a list could be prepared of the principal domestic woods for which substitute species are needed: This list, to be a helpful guide to tropical research, should include information as to the board footage of the wood consumed by the American market, the principal uses of the wood, the principal properties and characteristics which would be required in a substitute, the approximate average dimensions of f.a.s. selects and No. 1 common in the domestic wood, and whether the consumer could afford to pay a premium for larger average dimensions in a substitute wood, whether the demand is primarily for $^{8}/_{4}$ and thinner or whether there is a large demand for thick planks, whether pin-wormy lumber in the substitute wood could be used for some purpose, whether the wood is used both for lumber and veneer and if for veneer whether for rotary cutting or slice cutting, and finally the present prices at which grades of No. 1 common and better are being sold.

It is desirable to have in mind that tropical hardwood trees as found in virgin stands have greater diameters and lengths than most domestic hardwoods. For this reason it is easier to obtain from tropical hardwoods lumber of large average width and length than from domestic hardwoods. Furthermore, the predominant defects in tropical hardwoods differ from the defects found in domestic hardwoods. In tropical timber the principal defects are usually pin worms and heart defects, whereas in domestic hardwoods the principal defects are usually large, scattered knots. As a rule it is easier to obtain clear boards of large dimensions or clear thick planks from tropical hardwoods than from domestic hardwoods, so that wherever lumber of this type commands a premium, the tropical wood has an advantage. With the exception of the Philippine Islands, tropical logging is selective, i.e., trees of certain species are located and hauled out of the forest, but no attempt is made to utilize the forest as a whole. This process of selective logging is necessarily expensive. For this reason it would seem wise at first to concentrate upon finding substitutes for domestic woods having an average sales value of $100 per thousand board feet or higher for grades of No. 1 common and better.

If it is found possible to market in this country a number of the common species of tropical woods, the cost of logging could be materially reduced because of the increased yield per acre of forest worked.

As soon as those interested in tropical woods are placed in possession of information as to the types of wood for which substitutes are needed and the price at which the substitute wood can be sold provided it has the desired characteristics and properties, arrangements can easily be made for bringing in sample shipments of woods having the general characteristics desired. It would then be necessary to arrange facilities for laboratory tests to compare the proposed substitutes with the domestic wood. If these tests showed the substitute wood to have real promise, it would be desirable to have the principal consumers

[8] President, Astoria Importing & Mfg. Co., Inc., Long Island City, N. Y. Mem. A.S.M.E.

of the wood concerned arrange to make practical tests of the substitute.

It is well known that certain tropical woods have special qualities which no domestic woods possess. There are in all probability consumers looking for a wood with special qualities but they are unaware that such a wood is available and are therefore using an unsatisfactory wood or some other substance.

For example, there are known to be tropical woods which are very hard, very heavy, and extraordinarily durable under the most trying conditions. These woods are expensive to bring out and expensive to manufacture into lumber, and the price at which the lumber would have to be sold would seem prohibitive except for some special purpose. On the other hand, it is quite possible that certain consumers would be glad to pay a comparatively high initial cost to avoid constant replacement where replacement is difficult and expensive. It is necessary, however, that those familiar with tropical woods should know of the special need in order to fill it.

In brief, there are thousands of different woods in the tropics exhibiting a wide range of wood properties and characteristics. The easiest, quickest, and least expensive method would seem to be to ascertain first the type of wood that is needed and the price at which it can be sold, and then search for a wood of that general type in the tropics. Otherwise it is necessary to bring in thousands of samples of woods in the hope that out of the number some may be found which will prove satisfactory substitutes for domestic woods and can be sold at a price to compete with domestic woods.

H. M. Curran.[9] My own experience, covering many years of exploration and exploitation of tropical timbers, has convinced me that the timbers the world needs exist in large quantities in the tropics, can be produced economically, and that the price levels are at present such that the better grades can flow into our markets without prejudice to our timber business.

These interests will be benefited rather than harmed by these tropical timbers, for they will flow through their mills and sales organizations, helping them to retain their markets against substitutes. There need be no fear by American lumbermen that these timbers will replace the well-known woods of America.

Less than 20 per cent of the product of a tropical mill will probably be exported, and this only high-grade. The remaining 80 per cent will enter the channels of trade in the country of its origin.

[9] North Carolina Department of Agriculture, Division of Markets, Raleigh, N. C.

WDI-50-10

# Our Need for Knowledge of Tropical Timbers

## Rapid Waning of Supplies of Virgin Timber in This Country Calls for Extended Use of Tropical Woods, Whose Properties and Uses Must Become Familiar to the Industry

By SAMUEL J. RECORD,[1] NEW HAVEN, CONN.

WHAT interest has the American lumber industry and American forestry in tropical timbers and forests? Of what advantage would it be to our nation to have reliable information concerning the forest resources of our southern neighbors? If lumber from foreign sources is a potential competitor of the produce of our own sawmills, why not make stronger the barriers of ignorance and prejudice rather than try to break them down? Why should the School of Forestry of Yale University have any concern in these matters outside the realm of pure science? And why should The American Society of Mechanical Engineers consider the problem of tropical woods worthy of serious consideration?

To those familiar with conditions the answers seem obvious. Our lumber industry, in its manifold ramifications, is one of such vast and fundamental importance to the prosperity and general well-being of our nation that any thing that affects it affects the welfare of all our people. If this industry is imperiled, it is the duty of those who sense the danger to raise their voices in warning and to take such other measures as are within their power to anticipate any emergency and reduce the seriousness of its effects. Those in the best position to know believe that our lumber industry is now facing such an emergency as a result of the prodigality with which it has been consuming its raw materials without adequate provision for their replacement.

Warnings of an approaching timber famine have been given many times in the past, but changing conditions, especially the extension of transportation facilities into more and more remote localities, have postponed the day of reckoning. An unfortunate economic situation, particularly with reference to excessive taxation of standing timber, is forcing the too rapid cutting of the remnants of our virgin forests, and the resulting abundance of lumber on our markets gives the false impression that there is a corresponding abundance of standing timber.

### The Timber Situation in the United States

The timber situation of the United States has been made the subject of careful investigation by our Federal Government. The whole expanse of our country is known, its forest resources have been inventoried, and the factors of increase and decrease calculated. It requires no gift of prophecy to check our outlay against our forest capital and income and compute the result. The agency best qualified to do this is the U. S. Forest Service, and in this connection attention is called to a highly informative article by Chief Forester W. B. Greeley, entitled, "The Relation of Geography to the Timber Supply."[2]

> Most of the industrially aggressive nations [says Mr. Greeley] have lived in forested regions, and most of them have been liberal users of timber. The course of these nations in satisfying their requirements for forest-grown materials has usually run through three different stages. At first they have cut freely from their own virgin forests as long as the supply lasted. Then they have cast about for what they might barter from their neighbors. And finally they have settled down to the systematic growing of wood on all the land that could be spared for the purpose, still finding it necessary or convenient in many cases to import a substantial part of their national requirements from other countries whose virgin forests have not yet become depleted or whose timber culture produces an exportable surplus. . . . .
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> The United States is still in the first of these three stages. By far the greater part of the wood we use is still obtained from our own virgin forests. But the end of this supply is plainly in sight. The necessity is at hand of finding a new source of wood, either in timber culture on our own soil or in the forests of other countries. The consumption of timber in this country is so enormous that the problem assumes staggering proportions. We use annually about 12 billion cubic feet of saw-log timber, or nearly half of the quantity consumed in the entire world. Our use of all forest products, including pulpwood, railroad ties, mine timbers, and fuel wood, aggregates $22^1/_2$ billion cubic feet, or about two-fifths of the yearly consumption in the entire world.
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> Other countries which have likewise exhausted their virgin forests have found new sources of wood either in the practice of forestry or through imports from their neighbors or by combining both of these methods, without sudden industrial upheavals or serious timber famines. Their consumption of forest products has been relatively small; the change was gradual and usually involved no great difficulty. The enormous use of wood in the United States, however, and its intimate relation to national living standards, manufactures, and basic industries like agriculture, mining, and transportation, make our problem far more serious. We must find, almost overnight, a fresh source of raw material sufficient to supply 60 or 70 million tons of forest products annually. Instead of a gradual industrial evolution, the change is coming with the suddenness of an economic crisis.

Further along in the same article he says:

> The stern facts of geography have largely controlled these past developments in our forest industries and in the cost of their wares to the American consumer. The true measure of timber supply is not quantity but availability. Sixty per cent of all the wood that is left in the United States and 75 per cent of its virgin timber lies west of the Great Plains, whereas two-thirds of the population and an even larger proportion of our agriculture and manufactures are east of the Great Plains. The forests bordering the Pacific Coast contain over a trillion board feet of virgin stumpage. At the most, they will not supply our present consumption very long; but already the unbalanced geographical distribution of this resource is creating well-nigh famine prices in the parts of the United States where forest products are used in the largest quantities.

Of course the ultimate solution of our timber supply is to be found at home where there is an abundant supply of land which can be and should be devoted to forestry practice. We must look to the time when lumbering is stable rather than nomadic, when timber is cropped rather than mined, when our now idle lands are keeping our wood-using industries supplied and keeping thousands of people in permanent employment. These are ultimate aims, but what of the immediate future? How are we going to meet "the change that is coming with the suddenness of an economic crisis?"

It is interesting to note that foremost of the suggestions the Chief Forester makes in this connection is that "we must get all the foreign wood that we can to tide over the lean years, and we must go after it intelligently and systematically. For one thing, a thorough study should be made of the resources available in the hardwood forests of Central and South America, and their utility for the replacement of our rapidly waning supply of native hardwoods."

### Need for Identification and Classification

Here then is a very definite task at hand for those who are will-

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[1] Professor of Forest Products, Yale University.

[2] *Economic Geography*, March, 1925.

Presented at a meeting of the Metropolitan Section of the A.S.M.E., New York, February 24, 1928.

ing and qualified to do it. My own interest in it began back in 1916 when the Yale School of Forestry extended its field of endeavor to the tropics, particularly tropical America. It has been pioneer work in a vast region with one man, at the most two, with very little assistance of any kind and very limited funds, hence you will appreciate how far we are from having exhausted the subject! In fact, to be able to make any appreciable showing at all it has been necessary to emphasize special lines of work, particularly the identification and scientific classification of the trees and woods. While on first thought this may seem to be only of academic interest, as a matter of fact it is fundamental. Of what use are reports on woods unless one knows exactly what woods are meant? To thread the maze of vernacular and trade names requires patient and painstaking research, often extending over years and requiring many collections of specimens from the living trees in the forest. Timber cruisers in strange forests are largely dependent upon native guides for the names of trees, and when one takes into consideration the various languages and dialects spoken even in the same locality, the anxiety of the guides to be accommodating to the point of invention, and adds to it the cruiser's attempts at phonetic spelling, the only surprising thing is that the reports are at all intelligible. The wise cruiser brings out wood samples and other specimens for identification. Such specimens not only show what kinds of timber are there, but also, if properly determined, give him the benefit of all the information that is available about the same or closely related species from other localities and countries, and frequently point the way to the proper market.

The question of the correct naming of woods is of far-reaching importance. The introduction of new and untried timbers into our market is usually a slow and expensive process, and the temptation is always great to resort to subterfuge and deceit. Those who stoop to mislabeling their lumber are blind to their own interests, because no business founded on abuse of confidence can long succeed. Many a wood which could have won favor on its merits has suffered irreparable injury because its promoters forced upon it the reputation of an impostor. Until foreign woods can be brought in and sold for what they are, they should be kept out, since misappropriation of a valuable trade name is unfair competition and serves to degrade the whole lumber industry.

The tropical woods available for introduction in quantity into this country represent a wide variety, but for the most part they are not in the high-grade furniture or cabinet-wood class. The popular conception that all tropical woods are hard and heavy, or finely figured, or noted for their beauty of grain and color, is all wrong. The abundant kinds are the commonplace ones, useful but often not beautiful. They are called hardwoods to distinguish them from the pines and spruces and cedars which are called softwoods, but some of these hardwoods are lighter than cork and as soft as the pith of a cornstalk.

Tropical woods are for the most part of species and tree families different from those with which we are familiar. Beech, birch, maple, hickory, ash, and the other kinds we know so well and upon which our hardwood industries are built, do not grow in the tropics. One may find oak and certain other temperate-zone trees within the tropical belt, but mostly only at high altitudes. There is pine in Mexico and portions of Central America, and the lumber can enter our market without difficulty because the trade is familiar with pine and knows how to size up a new lot very rapidly. When it comes to judging tropical woods by American hardwoods the situation is more complicated because the new kinds are different. Being different, however, implies neither inferiority nor superiority: it merely means that some time and effort must be given to acquiring the information necessary to successful utilization. If the same trees grew in the forests of the United States they would be utilized as fully and in many instances as satisfactorily as are the ones actually here.

There are many problems involved in the introduction and utilization of unfamiliar woods. There are two ways of going about a solution. One is the slow, wasteful, and haphazard method of leaving things to chance and individual effort. The other is through the cooperation of various scientific agencies and trade interests. The latter method will give results quickly, and the knowledge gained will be of service to our lumber industry and manufacturers where it is most vitally needed. The cost, which would be almost prohibitive for a single institution or concern, would impose no appreciable burden upon the wood-using industries if properly distributed. And no matter what the outcome of such investigations may be, the knowledge gained will have a value far exceeding its cost. Delay in acquiring this knowledge can mean only loss.

### Desirability of Introducing Tropical Woods

The American lumber industry should not be antagonistic to tropical woods. Our native woods are not going to be driven off the market. If any American wood goes off the market it will be because the supply fails, and there is no likelihood that the supply of any important timber will fail completely. Before that time comes it will be found worth while to practice forestry, the eventual and only satisfactory solution of any country's timber problem.

An older generation of lumber dealers would be lost in a lumber yard of today. Carpenters and builders in the East are now familiar with Douglas fir, Pondosa pine, Idaho white pine, western spruce, western hemlock, Port Orford cedar, redwood, sugar pine, and other West Coast products, as well as Baltic spruce and other kinds of lumber from the Old World. Much of this change has come about in the last ten years, but in a way it has been going on from the beginning of things. People used first the timber nearest at hand, gradually extending farther afield and discovering unexpected virtues in woods they previously had scorned. Lumber from far-away points has not driven out white pine, northern spruce, southern pine, and cypress—it merely supplements them. It all makes for a new kind of competition, but it is better for the lumber industry that the competition should be between different species of wood than between wood and wood substitutes.

In the case of tropical woods it is better for the lumber trade to accept and become familiar with them and, in fact, welcome them, rather than to fight them and try to keep them out by erecting artificial barriers, such as a protective tariff. Foreign woods can succeed here only when there is a demand for them at a price that will permit a profit to the producer and importer, and such a demand implies dissatisfaction on the part of the buyer with the native material offered him—whether it be price, or quality, or something else. To fight the foreign woods simply because they are foreign is not an act of patriotism and will play directly into the hands of the wood substitutes. Eventually we shall grow most of the timber we need, but so long as we continue to cut it four or five times faster than it grows, it is certainly high time to be looking around for an outside supply to tide us over a strenuous period of readjustment.

The work that is needed to be done has already been carefully outlined. The agencies to do it are available and willing. It remains for those who would profit most from these investigations to furnish the means for carrying them out. Our tropical work at Yale has received no support whatever from the lumber industry. We are constantly appealed to for information and advice, but no funds are ever forthcoming from interested sources to make it possible for us to get the data necessary to answer

the questions asked. The only corporation that is contributing anything is the United Fruit Company. This company is not in the timber business and does not expect any immediate or direct returns from its contributions, but it is interested in anything that promotes the welfare of the countries in which it operates. Our wood-using industries, on the other hand, have a direct and immediate interest in the future supply of their raw materials. In the words of our Chief Forester, "We must find, almost overnight, a fresh source of raw material sufficient to supply 60 or 70 million tons of forest products annually. Instead of a gradual industrial evolution, the change is coming with the suddenness of an economic crisis." Such is the situation. What are we going to do about it?

## Discussion

George P. Ahern.[3] This topic brings up at once the question, "Why such a discussion?" The answer lies largely in the story of the shift of centers of lumber production and the closing down of hundreds of wood-using plants due to lack of local supplies. Many hardwood users are disturbed by rising prices and the difficulty of getting suitable raw material. This situation has impressed the Main Research Committee of the A.S.M.E. sufficiently to authorize a study of the facts and an inquiry into the possibilities of new sources of hardwood supply. Such an inquiry leads inevitably to the present greatest storehouse of hardwoods, the tropics, and the Tropical Plant Research Foundation of Washington was asked by the A.S.M.E. to undertake this work.

As the first step in this investigation a bibliography of tropical woods was prepared and a limited number of copies sent where it was thought they would do the most good. This list included wood experts in some thirty foreign countries. The issue met with a cordial reception. It was accompanied by a letter requesting cooperation in the preparation of a more complete second edition, and much new material was received and incorporated in that edition.

This research project seemed to arouse criticism as to its necessity, as it was claimed there was no shortage of wood supplies and no likelihood of any in the future.

To answer that criticism the writer undertook a survey of the present forest situation in the United States, going over reports and many scientific and commercial journals. The result of this study was incorporated in a paper entitled "Important Factors in Our Forest Problem," which has been submitted to the heads of the U. S. Forest Service and other leading foresters for comment and criticism with the following results.

Dr. A. F. Woods, the Director of Scientific Work for the U. S. Department of Agriculture, in a letter forwarding this paper to E. A. Sherman, Associate Forester of the U. S. Forest Service, stated: "I am sending herewith a very interesting and constructive survey of the forest problem in the United States. It gives a bird's-eye view of the situation and makes it clear that some strenuous work is needed to bring about a more sensible and economic procedure."

Mr. Sherman's reply to Dr. Woods included the following statements: "Major Ahern's statement of the situation is thorough and concise—Major Ahern's manuscript is a logical assembling of facts and opinions. It shows what the situation actually is. Major Ahern's assembled data lead one to the conclusion that the present trend of economic and political forces is heading the lumber industry into ruin both for itself and the natural resources upon which it is based."

Professor Hosmer, head of the Forest School at Cornell, states in a letter of February 4, 1928: "I wish most heartily to thank you for giving us the privilege of seeing this masterly presentation of the basic problem in regard to forests that faces this country. Your report has been read with the greatest interest by the members of this staff. I have taken the liberty of having the report copied in this office in that it contains so much material that is of interest."

A number of other comments of a similar character have been received from other leaders, and no denial of the facts and figures has been made.

As stated in the study referred to, recent reports by foresters in the field all point to a continued rapid disappearance of our remaining privately owned forests, with no check to this decline in sight. As far as our markets are concerned, but two forest regions of importance remain.

The virgin forests of the South are doomed to disappear within ten years at the present rate of cutting. The virgin forests of the Pacific Northwest will disappear or be withdrawn from the market within 20 to 30 years and probably less, as increased demands on this last virgin stand shorten the period.

According to these reports, no serious attempt at better logging practice is evident. Fire protection as a rule is for standing timber and not for cut-over lands. Unregulated slash is the rule, and accounts for many of the destructive fires each year. These reports state that some 60 per cent of the cut-over land is restocking rather unsatisfactorily, and 40 per cent is left practically denuded. Recurring forest fires add annually to the denuded land, and render less productive the remainder of the cut-over land.

The forest-fire situation is disheartening. A few years ago forest fires swept over $7^1/_2$ million acres annually; today the annual acreage fireswept is beyond 24 million.

The annual drain on our forest stock makes a huge total and continues despite depleted capital stock. In 1919 this depletion was estimated at four times the annual growth, a figure which today is much too small.

The national forests, comprising about one-fifth of our total forest area, furnish but three per cent of our wood needs. The farmers' wood lots, some 150 million acres, are mentioned in numerous reports as in decadence and approaching extinction.

Even Colonel Greeley, the head of the U.S. Forest Service, realizes the seriousness of the situation as quoted in the paper: "We must find, almost overnight, a fresh source of raw material sufficient to supply 60 or 70 million tons of forest products annually. Instead of a gradual industrial evolution, the change is coming with the suddenness of an economic crisis."

The most serious phase of this appalling situation is that with these facts well known at federal headquarters no undue alarm is felt over the early disappearance of our virgin timber, deteriorating second growth, destructive logging practice, and rapidly increasing forest fires.

These facts apply to both soft and hard woods. Hence the urgent need for inquiry into new sources of hardwood supply. The story of hickory is typical of what is happening to other valuable hardwoods in this country. In recent years the total drain on hickory has averaged about 400 million board feet annually, and the annual growth is but 84 million feet.

It must be remembered that we use in this country some eight billion board feet of hardwood annually and import but 200 million feet.

We must seek at once new sources of hardwood supply. The only region available for supply in quantity is tropical America. We may need to import within ten years some one to two billion board feet of hardwood. Much scientific research is necessary in the meantime. We must know the location of accessible forest areas, and the stands and distribution of timber; the properties, uses, value and availability of these woods—it

[3] Tropical Forest Research Foundation, Washington, D. C.

takes much time to get the facts—and then the market must be secured.

No country in tropical America is attempting to assemble these facts and seek a market for its timber. As we are the parties most concerned, we in this country must undertake the project of opening up new sources of hardwood supply.

Arthur Koehler.[4] The "overnight" in which we must find a new source of wood supply to which Colonel Greeley metaphorically alludes will not be a short one. But, while many of the wood-using industries are complacently sleeping or working overtime to fill a demand which they stimulated, some one must be putting in a night's work in getting ready to introduce the tropical woods which are to take the place of our diminishing supply of timber.

The introduction of new woods will not be an easy matter. First, the resistance of the wood-using industries themselves must be overcome. Manufacturers of furniture, musical instruments, tool handles, and automobiles will want to be assured that those woods compare favorably with walnut, birch, maple, oak, hickory, and ash, and that they will have no unexpected troubles in putting them through their plants, before they will buy them in carload lots. They also will want to be assured that more of the same kinds will be available for some time to come at practically the same prices. Next the resistance of the consuming public must be overcome. The buyer of furniture made from unknown woods will be suspicious that something cheap or inferior is going to be put over on him. Perhaps the question in furniture is not going to be so much, "How will this wood stand up in service?" as, "Is it the thing to buy?" Hence a public appreciation of the value of new woods must be developed. After the public is once accustomed to buying articles made of tropical woods, marketing difficulties will be largely overcome, provided, as the author points out, that the sale of new species of lumber falls into the hands of efficient promoters.

There need be no fear that the introduction of tropical woods will greatly upset existing lumbering operations. In the first place, because a market must be developed for new kinds of woods, they will come in so gradually that their inroads on markets of native species will not come as a blow to existing organizations. In the second place, indications are that tropical woods cannot be imported any cheaper than the cost at which native timber can be supplied as long as it exists. As native species, especially hardwoods, become depleted, the mill men, as a rule, would not be materially affected by the introduction of new species; in fact, many of them probably would want to get into the work themselves.

There may be some question as to what effect the opening of a new supply of timber in the tropics will have on the growing of a future crop of hardwoods in this country. In this connection it should be remembered that the area for growing hardwoods is greatly limited in the United States. Hardwoods demand fairly good soil, and therefore it is only the more hilly areas and inundated regions that will be used for growing hardwood timber. The more level and drained area will be taken up for raising agricultural crops as the population grows. Hence there is no prospect of an oversupply of native hardwoods, and whatever is grown always will have a decided advantage over tropical woods in the cost of transportation to market.

D. M. Matthews.[5] The author in opening his paper presents a number of questions which will naturally occur to the average individual when the subject of timber from the tropics and its use in this country is broached. Due to unfortunate economic conditions in the lumber industry of this country the average individual does not have the fact of an impending shortage of timber brought to his attention. Prices of timber have, it is true, risen, and risen sharply during the last two decades; but so have the prices of everything else, and only those of us who have been familiar with conditions in the lumber industry know that, in spite of these rising prices, production has been compelled to increase in such a rapid and competitive manner that there has been little profit in the business for the lumberman; and at first glance this would seem to indicate that we had a surplusage of timber in the country rather than any impending shortage. There are only a few of us, relatively speaking, who have had the incentive or the interest to look below the surface and determine the real cause of overproduction of timber in the United States, thereby learning that this overproduction is not a result of existing supplies of more timber than we need but is rather due to the existence of greater investments in the producing end of the lumber industry than current demands justify. It is this overinvestment of capital in lumber production in the country which has turned the industry into a nomadic one, forced concentration in production, and centralized production at the present day in the last big stand of timber in the country in the Pacific Northwest, where the rate of production is so great that although the current needs of the country at large are supplied, the end of the resource is in sight.

The author has fully and adequately answered the questions which he presented at the beginning of his paper. It is very clear that the capital invested in the lumber-production industry of the United States must seek investment in some other line of industry; and that the other industries which are built up largely upon the use of wood as prime raw material must greatly curtail their operations unless some other source of timber supply is to be made available to the country to take up the slack as between the time when our virgin resources are no longer capable of supplying our needs and that time, in the somewhat remote future, when we have put ourselves in a position to supply from our cut-over lands new stands of timber by reforestation. The author ends his discussion with another question, namely, "What are we going to do about it?" He has not attempted to answer this most important question specifically, but the writer is sure that he has very definite ideas as to what we ought to do about it and, indeed, the mere subject of his paper indicates that he is strongly of the opinion that, in this emergency, we should turn to the tropics and direct our energy and ability, as the first lumber-producing and lumber-consuming country of the world, toward the development and utilization of a great storehouse of timber wealth, heretofore largely untouched and, it is to be feared, considered by many of us of little importance or value.

Before proceeding to a somewhat tentative suggestion as to a means of answering his question, "What are we going to do about it?" the writer would like briefly to summarize the underlying facts which arise from a consideration of the paper:

1 There is a present and a still greater impending shortage of timber, and especially hardwoods, within the United States.
2 Prices are rising and substitutes for wood, too often unsatisfactory as regards either price or use, are coming into general utilization.
3 It is necessary to tap new sources of supply.
4 These are to be found in the southern Americas, especially Central America.
5 Woods of value to American industries which can be obtained from these sources are not coming forward in adequate quantities because:

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[5] Professor of Forest Management, School of Forestry and Conservation, University of Michigan, Ann Arbor, Mich.

*a* The qualities of these useful woods are imperfectly known;
*b* Existing sources of supply are unreliable and often untrustworthy; and
*c* No reliable data are available as to large potential sources of supply.

If we admit that these facts are incontrovertible we are forced to the conclusion that we must take some steps to make available to the ultimate consumer in the United States the timber which he will no longer be able to obtain from within the United States and which we know to be available elsewhere.

The writer has already said that the average individual is unaware that the country at large is faced with an impending shortage of wood material, and that in the long run this means that he will have to reduce his use of timber and resort to the utilization of timber substitutes often less satisfactory in use and almost always more expensive.

But we cannot expect to turn to the public at large for aid in this emergency except in so far as we can awaken public sentiment in behalf of the conservation of our remaining resources and enlist their support in programs leading to the creation of new forest areas. Nor does the writer think we should expect aid from the public in this direction. The public buys its timber from dealers who make it their business to supply it to them, and the dealers get it in turn from the capital which has become interested in lumber production. It is the interest of these groups which we must enlist if the problem is to be solved. There are four large groups of industry which it seems reasonable to suppose might be interested in the problem. These are:

1 The lumber industry
2 The wood-using industries
3 The manufacturers of milling and woodworking machinery
4 Tropical importers and dealers in hardwoods and timber from the tropics.

When this general subject first came up for consideration by the Wood Industries Division of the Society, the possibilities of obtaining the interest of these four groups were canvassed and it was felt that any attempt toward organization of effort in meeting the problem would naturally most appeal to the wood-using industries and that we could expect greater interest and possible aid from them than from any of the other three groups.

It was apparent right from the start that the lumber industry as a whole was not yet sufficiently educated or sufficiently aware of possibilities for investment in the tropics to look with sympathy upon any movement to develop timber resources in these regions. We expected indifference if not active opposition from the industry, and endeavored to avoid the discouragement of the one and difficulties which would arise from the other by not approaching them. We anticipated that they would answer in the affirmative the third of the author's queries: "If lumber from foreign sources is a potential competitor of the produce of our own sawmills, why not make stronger the barriers of ignorance and prejudice rather than try to break them down?" This expectation would be justified if we attempted to enlist the aid of the lumber industry at the present time. It does not follow that such would be the case ten years from now, when it seems probable that much of the capital so invested will be seeking reinvestment elsewhere. We did think, however, that we could expect the active support of the wood-using industries, but our expectations in this direction were not realized. It was found upon canvassing a large number of firms who were largely dependent upon the use of wood for the conduct of their business that, generally speaking, the wood-using industries felt that if any real effort in time and money was to be exerted in bringing to them new supplies of wood material from the tropics, such effort should be expected only from importers and dealers, and, by inference, from the capital which might invest in the business of producing lumber in the tropics. They generally admitted that they appreciated the problem and would be pleased to be assured of additional supplies of suitable wood material, but most of the individual firms approached did not seem to realize that it might be considered fairly up to them in their own interest to cooperate in the production of such supplies. Only a few firms which were already seeking their raw material from abroad and were therefore importers as well as users seem to be genuinely interested at this time. It must be admitted that this was rather a severe disappointment and a setback to the program we had under consideration. It indicated pretty clearly that more time must elapse and the pinch of shortage of supplies become more evident before active support from the wood-using industries at large could be anticipated. I think that we are safe in assuming that the time is not far distant when the active support of both the lumber-producing and lumber-consuming industries of the country can be obtained. In the meantime it appears to me that the answer to the author's question as to what we are going to do about bringing into the United States and utilizing the timber resources of the tropics lies, in its initial stages, with the tropical-wood importers and dealers and those larger users of high-grade woods who are already reaching out into the tropics to augment the waning supplies of woods suitable for their purposes obtainable within this country. From this group the inquiry which was set on foot a year ago last fall received very real encouragement, and if real cooperation on the part of this group can be obtained, the writer believes the necessary start can be made which will bring about the larger development in the future which the trend of lumber production and consumption in the United States so clearly indicates as an absolute necessity.

We now come to the question of the definite procedure to be adopted in obtaining such cooperation. The work which has already been done has resulted in the formation of a strong committee to consider the problem in all its aspects. It seems to the writer that the next logical step would be an appeal from this committee to selected firms and individuals who may be considered to have an active stake in the cold-blooded business of bringing into this country timbers from the tropics and marketing them at a profit, to form themselves into an association avowedly for the purpose of aiding themselves in placing tropical timber on the markets of the United States and thereby making money out of it. The old axiom that nothing succeeds like success is as true today as it ever was, and if such an association as has been indicated results in the pooling of the interests of the importers, dealers, and such consumers as wish to see an increase in the available supply of hardwoods in the United States, success will inevitably attend their efforts. Such success more than anything else is likely to attract the support and interest of others who would like to share in it.

Raymond J. Hoyle.[6] The paper gives the idea that the solution of the problem of our waning timber supply is to be found in growing more timber or in the importation of foreign woods or both. Not one word has been said about solving this problem of timber shortage by improved utilization of our native timber. Why must we go to other countries for new supplies of wood with all their attendant difficulties while we continue to waste our home material to the extent of from two-ninths or four-ninths of the annual drain upon our forests? Why is it not the best of economy partly to close the spigot of waste rather than import the timber of uncertainty to fill our fountain? This process only delays the day when better economy with our native timber

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must be practiced. Already we have a great number of native commercial woods which are not all at well understood, and which are all in severe competition for markets. Importation of unknown wood will only aggravate this situation.

The author says that lumber from remote points in the United States when brought into old territory in competition with species of long standing has not driven them out but has supplemented the earlier-used woods. In addition to supplementing them it has caused severe competition. Prices on lumber have dropped; there has been great confusion of sizes, grades, and properties of these woods. This great confusion has allowed competing materials to secure many markets which lumber should more properly occupy. What might the situation be if we import foreign woods?

He further says that carpenters and builders in the East are now familiar with our western woods. It is a fact that redwood and red cedar are frequently used interchangeably without a knowledge of the difference. All of our western pines are one grand jumble, and about all that is specifically known is that these woods are some kind of pine. West Coast hemlock, a wood of great merit, is put in a class with eastern hemlock by the public just because it bears the same name—hemlock. Douglas fir is condemned or praised depending on whether soft texture or young-growth material is used for particular purposes, and depending on whether the tree grows on the west slopes of the Cascade Mountains or elsewhere.

As a matter of fact, our knowledge of species in the United States is surprisingly lacking among carpenters, contractors, builders, and woodworkers of every description, and even after centuries of use of some of these woods, our best-trained men cannot answer many questions about wood. What will the importation of unknown tropical woods mean?

We must continue to use our wood rather than curtail its use, for this latter condition would not result in fo. st perpetuation. Use creates value and encourages timber growing. About four-fifths of our timber land is privately owned, and the growing of timber on this area cannot be expected until closer utilization is practiced. This problem of closer utilization is linked up closely with the economic problem of overproduction. Overproduction and competition are the causes of present-day low timber prices, and low lumber prices are not conducive to close utilization.

In conclusion, while the growing of timber is essential and desirable for our future needs, this practice is dependent on the solution of our economic and close-utilization problems. Imports of foreign woods in any appreciable amount will complicate our situation and delay the day when forest growth and use are on a more stable basis.

H. M. Curran.[7] We have more hardwood timber than our industry demands. Because of overcutting, the lumber industry is in as bad a way financially as the farmer. Price levels are high and quality low because we have pushed exploitation into the more inaccessible regions or used low-quality trees or small-sized trees left from earlier logging.

High-grade, medium-priced hardwoods must come from new virgin forests.

The strong point made by the author, namely, that we must in the near future find large supplies of wood of high quality if wood substitutes are not to drive our own well-known species from the market, is a telling argument to silence the opposition of those who fear the entrance of new hardwoods.

While the author's experience is less extensive as to field conditions than that of many of the tropical foresters, his intimate knowledge of the woods themselves is greater than of any person known by the writer today. When he states that these woods of the tropics have the qualities to supplement our own waning supplies, it may be taken as the expression of one who has weighed carefully all the existing evidence, and knows he is safe in the statement.

[7] State Forester, North Carolina Department of Agriculture, Raleigh, N. C.

H. P. Brown.[8] The accuracy of the statistics quoted by the author from Colonel Greeley's paper in the *Economic Geography* is unquestionable. Our available timber resources have been carefully inventoried, and, at the present rate of consumption, it is only a question of time before increasing scarcity will react seriously as an economic brake upon our future industrial development. Unfortunately some of the pioneers in the forest-conservation movement underestimated the timber still available and prophesied the lean years as coming too soon, and this has served to lull certain interests into a sense of security. The theoretical date of the complete exhaustion of our timber supply at the present rate of consumption has been pushed farther into the future, but leaner years in lumber production are as certain as death and taxes.

In a discussion of the possible utilization of tropical woods, it is well to bear in mind certain fundamental aspects of the question. We are utilizing our timber several times faster than we are growing it. Our reserve supply of soft or coniferous wood is proportionately much greater than our hardwood supply. Coniferous trees are trees essentially of the temperate zones; while they occur in tropical forests, the supply of coniferous timber is negligible. Conifers should be grown in the temperate zone, and it is most economical to grow them there. There is no reason why, using proper forestry methods, we should not grow, in the confines of the United States, all the softwood lumber that we require.

In the writer's opinion, once the original stands of our hardwoods are exhausted we shall never be able to grow them in sufficient quantity to meet our requirements. Hardwood trees attain their best development in the tropics, and it is here they show the best annual increment growth, speaking in terms of averages. Just as the dark races are the result of a tropical climate, working through generations, so are hardwood trees the result of tropical conditions. On the other hand, the white races belong to the temperate zones; so do the conifers.

Granting that we cannot hope ever to grow hardwood lumber in sufficient quantity for our needs in the United States, the question of tropical hardwoods comes to the fore; the demand for tropical woods is here to stay. Their utilization involves finding means of identification, the study of their technical properties in the laboratory to determine their proper uses, and investigations in the field to determine if sufficient supplies are available to warrant marketing at home. To do all this requires funds. No federal or state funds have been made available to date, and there is little likelihood of this possibility in the near future. But two of the forestry schools, Yale through the efforts of Professor Samuel J. Record, and the New York State College of Forestry at Syracuse through the writer's, have devoted any attention to tropical timbers, and this has been largely due to their enthusiasm on limited funds and in the writer's case to what is even more important, limited time owing to teaching responsibilities. Certain firms of importers have been shrewd enough to compile much information upon the timbers of districts in which they are financially interested, and in some cases at least they have employed scouts with experience in tropical forestry to make surveys for them. The lumber industry at large cannot expect to obtain much information from this source, however, as it is usually considered as con-

[8] Professor of Wood Technology, The New York State College of Forestry, Syracuse University, Syracuse, N. Y.

fidential, to be used for the advancement of their own monetary interests.

The writer would urge that the lumber industry set aside funds for the study of tropical timbers, not only of our American tropics but of those of the Old World as well. American capital is seeking outlets throughout the world. Foreign bonds at present are more attractive than domestic, and the American people are rapidly acquiring investments in the tropics. The study of tropical timbers should proceed as we acquire a better knowledge of the torrid zone.

The information upon tropical timbers should be made available to the whole lumber industry, not to the small coterie which is interested at present. The demand for tropical woods will increase mightily in the next decade, and the lumber industry at large should profit financially. Divide up the profits among you; there are enough for all.

Funds made available for the study of tropical woods, in the writer's opinion, should not be allocated to one school. A healthy competition in research between schools is desirable. Research fellowships of a thousand dollars a year would help materially in forwarding the study of tropical timbers. Men would thus be made available to carry on the work under proper direction, and they at the same time would receive a training which should render them valuable to firms engaged in the importation of tropical timbers. Not only for tropical timbers but for domestic timbers as well, the lumber industry can well afford to finance fellowships which will enable it to get men who are better trained in the structure and the physical, including the mechanical, and chemical properties of wood. The lumber industry, whether it be domestic or tropical woods, is competing with steel and concrete. The forestry schools are sending out their best men, but they are often outclassed for lack of training, for lack of understanding of raw-product wood. Agents must know "wood" to compete with steel and concrete engineers. The National Lumber Manufacturers Association is now engaged in a mammoth advertising campaign. How much more drive, how much more impetus, would be secured with properly trained men. The men now in the work are able, but blind men cannot fight. Four years at a forestry school is not enough. Scholarships are needed for additional years, and this applies for domestic woods and for tropical woods alike.

C. D. Mell.[9] The author asks five questions in the first paragraph. The writer's answer to the first two is, "None whatever." The third is not entirely clear. The last two questions he would answer most appropriately by the Latin-American slang "Quien sabe," meaning "Who knows."

Apparently, the object of the paper is to obtain contributions from organized business and scientific men so as to enable the author to send his students to tropical America to collect wood samples. He states that the United Fruit Company—not in the lumber business—is the only organized unit that is making funds available for enlarging his activities, implying that the wood industries are lacking in vision in not contributing to his project.

Moreover, the title of the paper, "Our Need for Knowledge of Tropical Timbers" apparently has reference only to tropical American timbers, as nothing is said regarding woods from the Philippines, for instance, which are tropical and which are now entering this market in rapidly increasing quantities. It is well known that the woods occur in undeniably large quantities in the Philippines, which are among our insular possessions, and can furnish us with the necessary supplies, when "we must find almost over night," borrowing Mr. Greeley's text, "fresh sources of raw material sufficient to supply 60 to 70 million tons of forest products annually."

The Philippine mahoganies, for instance, can come to our rescue and satisfy the author's final question, "What are we going to do about it?" At the hearings of the Federal Trade Commission, when the question of nomenclature was under review and notwithstanding the fact that there are over 30,000,000 feet of these woods now being used in this country and that all the users are satisfied, the author made statements which, if they could not be controverted, would greatly lessen the use of these very admirable woods in this country; their use was established at tremendous expense and hard work on the part of dealers, but the author asks for funds with which to seek other woods in foreign countries after he has discouraged the use of those that have been found available in our insular possession.

It is safe to say that no one who is measurably acquainted with the lumber business or with some phases of the wood industry and their relations to the supply and demand of lumber will be alarmed by the statements of Mr. Greeley and the author. They appear to be unaware of the frequent recurrence of predictions of a complete exhaustion of our domestic lumber supply. More than 150 years ago a fear of a timber famine was in the minds of many in America, and it was suggested that the only means of averting a serious economic crisis was to plant catalpa trees on all available lands not needed for agriculture; the catalpa tree is a fast grower, but it remains too small to produce lumber logs.

Our period obeys the same process, and the author's proposal is in line with the catalpa plantation scheme. Since the early timber famine reports, the lumber industry continued to prosper; it survived and assumed increasing proportions, and even now the common complaint is among wholesalers that the demand is poor and that selling their mills' output is getting more difficult. The lumber substitutes are rapidly gaining ground, and we now read accounts of the fact that the lumber industry is spending two million dollars annually in an advertising scheme designed to discourage the use of the lumber substitutes.

If the author should succeed in finding the woods he imagines are somewhere in tropical America, the lumber industry would probably have to spend another two million dollars annually in order to discourage the use of foreign woods and to enable the mill owners here to sell their domestic lumber in the home markets.

The author takes it for granted that his scouts will find an abundance of good timber the wood-using industries can use, but apparently he has no first-hand knowledge of the tropical bush and does not realize that the American tropics outside of limited areas in southern Mexico and perhaps parts of British Guiana are almost depleted of timber. Dr. John Gifford, the father of American forestry, once said that there is a lot of wood in tropical America, but that very little can ever be used here; he also stated that if we want just *wood*, we have plenty right here in the United States.

In the foregoing the writer has endeavored to point out reasons why the lumbermen and woodworking concerns can have no faith and little or no collective interest in helping defray expenses incident to searching for woods in tropical America. The republics to the south of us import from the United States the bulk of the structural timbers as well as the common lumber they use. These countries cannot furnish their lumber requirements from their own forests; therefore it is inconceivable to believe that the author could find enough of available material not only to satisfy the local needs, but also to ward off Mr. Greeley's predicted economic crisis in the United States.

[9] Tropical Forester, I. H. Monteath Co., New York, N. Y.

# Problems of Design for Mass Production in The Furniture Industry

## An Application of the Line Method of Assembly to the Manufacture of Office Desks

By BAYARD EDWIN RICHARDSON,[1] GRAND RAPIDS, MICH.

WHILE the title of this paper is broad enough to encompass the furniture industry as a whole, it is not the purpose or intention of the writer to set forth the full possibilities of design for mass production in every branch of the woodworking industry. Such an undertaking would require the combined efforts of many men selected from diversified branches of the industry, and their combined knowledge, properly compiled, would more fittingly embrace the entire thought expressed in the title.

The subject of this discussion will be confined more particularly to the problems of design for mass production in the manufacture of commercial furniture. While the principles involved are now in general use in the automotive industry, the application of these principles to the manufacture of office desks will disclose a new departure in this branch of the furniture industry.

All previous conceptions of structural design have been abandoned, and while external appearance has been only slightly altered, the component parts of the desk have been radically changed.

These changes in structural design have brought about marked reductions in manufacturing costs, greater strength in the assembled products, and best of all, a method of assembly which permits the use of the principles of mass production now so successfully used in the automotive industry.

### Line Production

Modern industry is indebted to the automobile for the principle of line production, and production engineering has without doubt achieved more through the automobile industry than through any other industrial development. But the application of these principles to the manufacture of furniture has been slow. It is surprising and almost unbelievable that an industry which has been in existence for centuries should be so slow to take advantage of the production methods developed by and universally used in this much younger industry.

Surely the furniture plants can boast of marked improvements in their manufacturing processes—for marked changes in plant management and machinery methods have come to light in recent years in every branch of the wood-working industry. It would not be fair to say that the automobile industries have a monopoly on all of the engineering brains of the country for there are many shining examples of accomplishment in the direction of production engineering in a number of the larger woodworking plants of Grand Rapids and other cities having similar industrial plants. Nevertheless tne fact still remains that none of these has, as yet, taken full advantage of the principle of line production. Just why should this condition prevail in our industry?

A careful analysis of the problem of line production as applied to our particular product has brought to light many interesting facts regarding structural design for large production. It has given us a better understanding of the relationship of these two factors, which play such an important part in the manufacture of any product.

### Production by the Conveyor System

It has been demonstrated conclusively by all of the large automobile plants in this country that by means of a production line, it is possible to carry on assembly operations at a predetermined rate of speed; operators must keep up; materials must flow to the assembly line; the finished product must drop from the end of the line at scheduled intervals; and lowered costs are bound to result from such a program.

The mechanical conveyor has become the backbone of the materials-handling system. Materials must be handled with greater dispatch and less demand on floor space. The conveyor must be kept moving. Various types of power-driven conveyors have been developed to meet these demands.

Electric screwdrivers and socket wrenches have been in the course of development for many years and within the last two or three years have supplanted laborious hand methods, particularly in line-assembly operations.

All production is a matter of time. It is the basic factor in every production schedule. Time and speed are synonymous, because change of speed means a corresponding change in production time. Speed flexibility is therefore vital. To be able to change the time production of any machine it must be flexible in speed. There is one best speed for every operation.

The day's production and the number of men on the line determine the speed of the assembly conveyor. Variation of quantity per unit of time or in the number of operators at work calls for an adjustment in speed of the assembly conveyor.

All production machinery must be flexible.

In order to take full advantage of the power-driven assembly conveyor, it is necessary to have all parts entering into the assembly completely processed from raw material to a state of completion before being fed to the assembly line.

A high degree of accuracy must be adhered to in the production of parts, to insure quick assembly.

In the use of sub-assembly operations the number of operations carried out on each unit is reduced to the minimum, at the same time quantity production is at a maximum. This plan shortens the final assembly operations, and permits the use of a shorter assembly conveyor, with fewer men to maintain a desired production schedule.

At each operator's station along the assembly conveyor are the tools necessary for his particular part of the work. As the conveyor passes along, each operator contributes his share of the work. The separate parts which enter into the assembly are brought to the line at proper intervals. This insures constant flow of materials.

### Changes in Construction of Desks

To apply these principles to the manufacture of any product requires a large volume of sales. Without large volume of sales no real production schedule can be entertained. The economies resulting from mass production depend primarily on quantity. The larger the quantity, the greater are the economies to be made.

The sales possibilities in the commercial-desk field are very great. It goes without saying, however, that sales will invariably increase with every decrease in retail price. This

[1] Plant Engineer, Stow-Davis Furniture Co.

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has been the impelling thought back of our efforts in attempting to apply the latest principles of mass production to our product.

Early attempts to fit any of our desks, as they were then being built, into the production picture just painted, disclosed the fact that the construction was all wrong. The construction of our desks, like all other pieces of furniture, had been developed to fit the age-old art of cabinet making. It required the skill of a cabinet maker to assemble our product. To dissect that art for distribution along an assembly line meant the teaching of many new tricks.

This procedure was useless because only minor economies could be gained. It still remained that the total number of operations were practically the same, whether done at the cabinet maker's bench or on the assembly line.

Thus it became evident that some new construction, some new way of putting wood together, would have to be developed to permit the use of line-production principles; a construction which would eliminate the cabinet work, the hand-fitting and gluing operations now in common use in all furniture plants.

Every known method of detail construction used in the furniture industry was given careful consideration in an effort to determine a suitable means of applying the principle of line production to the manufacture of desks. We were determined to effect the greatest possible savings in machining operations, as well as in the final process of assembly.

None of the present woodworking methods of construction seemed to fit all of the requirements named, so they were all laid aside and forgotten completely for the time being while a search for new ideas in construction went forward.

### Combination Wood and Steel Construction Adopted

Careful consideration of automobile-body construction disclosed the fact that steel and wood can be combined advantageously, and this thought served to direct our efforts in working out a new construction.

Considering for a moment the general details of any commercial desk, it will be apparent that they are all built along one conventional line, and are very similar in general appearance. Compared to the finer types of executive office furniture, the average commercial desk is severely plain and lacking in beauty. All have plain square corner posts, plain end and back panels, square-edged tops, and drawer fronts lacking any trace of ornamentation other than some cheap type of wood or metal pull. The corner posts usually terminate at the floor with a brass cup or socket.

To develop a new type of construction for desks without improving the general appearance to a marked degree, would be falling short of the desired goal. From the sales standpoint alone a marked improvement in exterior design over the general run of commercial desks would be an advantage.

With all of these facts directing our efforts, a new desk construction gradually developed, having an interior framework of steel and an exterior of wood—assembled without the use of glue and without the skill of a cabinet maker.

### Structural Details of the New Desk

Square corner posts were abandoned, giving way to rounded corners formed by laying up the end panels of the desk in specially built cauls which bend the five-ply veneer to the desired shape at the ends, at the time of applying pressure. This eliminated the solid wood used for corner posts, and all the machining operations necessary to attach the end panels to them. These new panels are used both on the ends of the desk and in the well space, two panels being used to form the sides of each pedestal of the desk.

Top and bottom pedestal frames or plates are formed of steel, having grooves pressed into them to receive the end panels, while inside of this assembly is located the steel frame formed of angles spot-welded together in such a manner as to provide slides for supporting the pedestal drawers.

At the corners and on the under side of the bottom pedestal frame are steel cups spot-welded in place which receive the upper ends of the turned wood legs of the desk. These turnings are bored to permit a bolt to pass up through their center, and are provided with a pressed-bronze cup at the floor line. The bolts referred to pass up through the legs, base frames, and top frames of each pedestal and serve to clamp the complete pedestal assembly rigidly together. A small back panel closes the back of each pedestal and is securely clamped in position between the top and bottom frames along with the end panels.

Between two such pedestals is located the well-drawer frame which is also fabricated of steel. This is secured to the end panels of each pedestal by means of bolts. The five-ply desk top is secured to this completed assembly by means of wood screws which pass through holes punched in the top pedestal frames.

All steel parts making up the inner frame of the desk pedestals are stamped from cold-rolled steel, and when spot-welded together make a rigid assembly, resembling in appearance the familiar steel structure of the modern skyscraper.

The drawers used are made of wood, with the conventional dovetail construction at the corners and three-ply veneer bottom panels completely framed in. These are assembled in a specially designed air clamp, which insures uniform pressure at all dovetail joints and perfectly squares the work at one operation.

All machining operations on the wood parts entering into the new desk are being done with particular attention to accuracy in dimensions, on production machines of the very latest type, steel snap gages being used for checking each set-up.

Careful attention was given to the design for interchangeability of both the steel and wood parts entering into the construction of the various sizes of desks.

It will be apparent from the description given that the completely assembled desk, from the exterior viewpoint, is primarily an all-wood desk, having an interior superstructure of steel, greater in strength than that of wood.

Only the base molding and the narrow beads between the drawers in each pedestal are exposed steel. These surfaces receive a natural wood-grain finish before reaching the final assembly line, and match the finish of the wood perfectly.

### The Finishing Room

One great advantage of the new construction lies in the fact that the component parts can all be put through the finishing room before proceeding to the assembly line. This feature led to the use of a mechanical conveyor for the finishing of all parts.

The conveyor is of the roller-chain type having wood slats which form a continuously moving table 24 in. wide and 50 ft. long—passing through the spray booth and ventilated drying tunnel, from which it emerges sufficiently to permit unloading.

A variable-speed drive provides adjustment of travel to meet every requirement. This system of finishing reduces the problem of spraying lacquer down to the terms of square feet of surface covered per minute of time. It insures a uniform coverage on all surfaces which pass before the operator stationed within the spray booth.

The drying tunnel carries off the fumes which are emitted from the wet lacquer surface in the drying process. Temperature and humidity control, together with a constant change of air in the tunnel, insures a uniform drying rate for the finish and eliminates the element of chance in the finishing room.

These ideal conditions hasten the drying process so that all parts can be readily handled when discharged from the end of the conveyor, where they are placed in portable racks and allowed to stand a suitable length of time before being rubbed.

Portable racks serve to carry the finished parts to the stock-room which is parallel to and on both sides of the assembly conveyor. This arrangement supplies every operator on the assembly line with the correct parts to carry on his part of the construction process.

### Advantages of Line-Assembly Method

A power-driven mechanical conveyor similar in construction to that used in the finishing room, and approximately of the same length, serves the process of assembly. This is also provided with a variable-speed drive, permitting a variation of from 1 to 3 ft. per min. to meet variations in the production schedule.

One of the great advantages of this entire process of line production lies in the fact that orders received in the morning's mail can be delivered from the assembly line to the packing room for shipment by noon of the same day. This is a condition never before attained in the furniture industry. It is one of the most important developments resulting from our study of structural design for mass production.

From the standpoint of exterior design, the new construction lends itself readily to modification in detail. Drawer fronts can be overlaid with fancy woods, or shaped on the face. They can be made flush front, without bar rails between each drawer. Different turnings can be used to fit any period in design for the legs of the desk, and fancy woods may be applied to end panels, back panels, and top. Character changes in the base molding are aso permissible without affecting materially the interchangeability of structural parts. Thus a number of patterns differing in external design can be assembled at will from the stock racks carrying the finished parts.

A more desirable manufacturing schedule than this could hardly be hoped for.

### Economies Resulting From New Construction

Before bringing this paper to a close, it might be well to point out some of the manufacturing economies resulting from the new construction.

First of all, a marked saving in materials and labor can be realized from the substitution of steel for wood in building the framework.

Greater accuracy can be maintained, thus eliminating all hand-fitting operations at the time of assembly.

All gluing and clamping operations have been discarded for a much quicker form of assembly, which can be done by unskilled labor in minutes, as compared to hours for cabinet making.

Finishing costs have been lowered considerably as a result of the continuous flow of parts through the spray booth as against the method of finishing a fully assembled article.

The total number of machining operations on all wood parts has been reduced. Those remaining have been simplified to fit into only the faster cutting operations performed by the latest types of wood-working machinery.

Many smaller savings have resulted from quicker processes of handling materials in various departments by methods which have been omitted in this article for the sake of brevity.

In conclusion, it is hoped that this new development in the manufacture of commercial furniture will point out more clearly the relationship of structural design for mass production in other branches of the woodworking industry and the fact that the old order of things can be departed from in this day and age of competition.

New methods of construction must be developed before line production and assembly principles can be fully applied to the manufacture of furniture.

## Discussion

The Author, in answer to many questions, brought out the following points: The upper frame of the desk is of steel, and has a projecting lip around the upper part of the pedestal, through which ordinary wood screws pass up into the top to fasten it in place. The five-ply top referred to is of conventional construction, heavy core stock with cross-pinning on both sides and face veneer. The desk is to be put on the market in two grades, one a commercial grade and the other lending itself more particularly to use in executive offices. There will be a $1^1/_4$-in. top on the commercial grade and a $1^1/_2$-in. top on the better grade.

The rate of speed of the conveyor through the spray booth is adjusted to give the proper coverage on unit of area, in unit of time, we will say. The operator covers the surface as it goes by and there is very little lost motion. We find that the rubbing operations are done in much less time if the parts are accessible than when finishing the completed desk. A desk is a large, bulky piece of furniture and must be handled; there are many angles and corners to get into, and curved surfaces and inaccessible places that take time. We are now finishing all separate parts as they pass long. Each man does his operation as it moves along.

No attempt has been made to measure the quantity of lacquer used. In fact many things referred to in the paper are only just emerging from the stage of experimentation. It will be noticed that no reference has been made to any exact detailed savings. It is hoped that figures will be available soon which will prove a number of the broad claims made here.

It is going to take about five minutes with the combined efforts of a number of men, to completely assemble one of the desks from the start to the finish.

We have tried to retain the beauty of wood desks by making the entire exterior, so far as construction permitted, of wood, and using steel only in the interior for such parts as are better made of steel. The minimum of steel shows on the face of the desk. I do not think we have sacrificed anything in appearance by the use of steel. Through actual tests, we find the sample desks turned out are far superior in strength to desks made as well as it is possible to make them entirely of wood.

# Compressive Tests of Balsa Wood

By A. H. Stang,[1] Washington, D. C.

BALSA wood has been used on several occasions to insulate machinery so that the vibrations would not be transmitted to the floor, and has apparently proved successful for this purpose. Since few data are available on the compressive properties of balsa wood, the United States Bureau of Standards conducted tests to determine how much shortening took place under a uniformly distributed load, how much permanent set remained when the load was removed, and the compression-time relations when the balsa wood was loaded by dead weights.

Eleven specimens furnished by the Balsa Wood Company, New York City, each 12 × 12 in., were used for these tests. Each specimen was composed of three boards, side by side and dovetailed together. Three were one inch thick, five were two inches thick, and three were three inches thick. Three of the specimens had been coated with a black paint which appeared to be a bituminous compound. These specimens will be referred to as painted, the others as unpainted.

Nine of the specimens were tested in compression by applying the load to the 12 × 12-in. faces through a large spherical bearing attached to the moving head of the testing machine.

The decrease in the thickness of each specimen under load was measured at the middle of each of the four sides by dial micrometers which were graduated in thousandths of an inch. An initial load of 10 lb. per sq. in. was applied, then the load was increased by increments of 10 lb. per sq. in. until the proportional limit had been exceeded. After each increment, the load was decreased to the initial point.

The deformations of the specimen were read at each load.

The set due to a given load was taken as the difference between the readings at the initial load after the given load and the first readings taken at this initial load.

At low loads the proportionality between the stress and the shortening of these specimens was remarkably close. It was therefore possible to find fairly definite values of the proportional limit from the stress-strain curves.

For stresses higher than the proportional limit, the compression increased more rapidly than the load, and consequently the load increments were increased and the tests were continued until the final thickness was about one-half of the original thickness.

Typical curves are shown in Fig. 1 for specimens of each of the three thicknesses. The proportional limits and moduli of elasticity together with the weights of the specimens are given in Table 1.

The specimens three inches thick were composed of pieces which contained the heart of the tree. These specimens had a lower density than the specimens one and two inches thick which did not contain heartwood. The tests showed that they also had lower proportional limits.

Lower values for the modulus of elasticity were found for the painted than for the unpainted specimens. They also had a higher density.

None of the specimens was perfectly elastic. The set after each application of load was in all cases a very appreciable part of the deformation under load and was, roughly, one-half of this deformation up to the proportional limit.

At higher loads the set became proportionally larger.

As with specimens of other materials having a large area compared to thickness, the balsa wood did not appear to have a definite maximum compressive strength. The load continued to increase as the thickness decreased.

A study of the test results of these nine specimens seemed to indicate that the density of the wood was an important factor in the strength properties of the material. For use as supports under heavy machinery, the different supports should have the same properties to preserve the level of the machine. Two other specimens, 2-D and 2-E, each two inches thick, were therefore prepared. Each specimen consisted of three boards joined to make the 12 × 12-in. surface, and these parts were selected so that both specimens had the same weight, as given in Table 1.

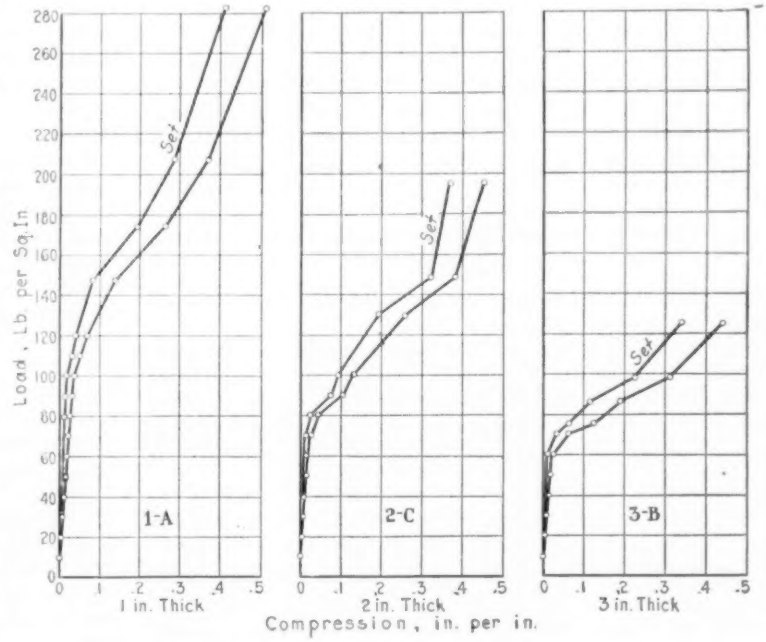



Fig. 1 Stress-Strain and Stress-Set Curves

TABLE 1 PROPERTIES OF BALSA WOOD SPECIMENS

| Specimen No. | Condition | Thickness, in. | Weight, lb. per cu. ft. | P-limit, lb. per sq. in. | Modulus of elasticity, lb. per sq. in. |
|---|---|---|---|---|---|
| (Tested in a testing machine) | | | | | |
| 1-A | unpainted | 1 | 7.76 | 85 | 2550 |
| 1-B | unpainted | 1 | 7.53 | 70 | 2400 |
| 1-C | painted | 1 | 8.40 | 75 | 1650 |
| 2-A | unpainted | 2 | 7.90 | 65 | 4200 |
| 2-B | unpainted | 2 | 7.68 | 95 | 3900 |
| 2-C | painted | 2 | 7.93 | 50 | 3600 |
| 3-A | unpainted | 3 | 5.06 | 36 | 3500 |
| 3-B | unpainted | 3 | 5.14 | 45 | 2500 |
| 3-C | painted | 3 | 5.67 | 48 | 2000 |
| (Tested under dead load) | | | | | |
| 2-D | unpainted | 2 | 9.76 | .. | ... |
| 2-E | unpainted | 2 | 9.76 | .. | ... |

[1] Engineer, Bureau of Standards, Washington, D. C.

Presented at the First National Meeting of the A.S.M.E. Wood Industries Division, Grand Rapids, Mich., October 17 and 18, 1927, and published by permission of the Director, U. S. Bureau of Standards.

Each of these specimens was tested under a deadweight of 15,000 lb. which was applied to the 12 × 12-in. face, thus producing a compressive stress of 104 lb. per sq. in. Vertical compressometers were mounted at the center of each of the four sides of the specimen to indicate the shortening produced by the load. They were subjected to this load for about seven days, readings being taken as indicated in Fig. 2, which shows the time-compression curves. The rate of compression for these two specimens, which had the same density, was practically the

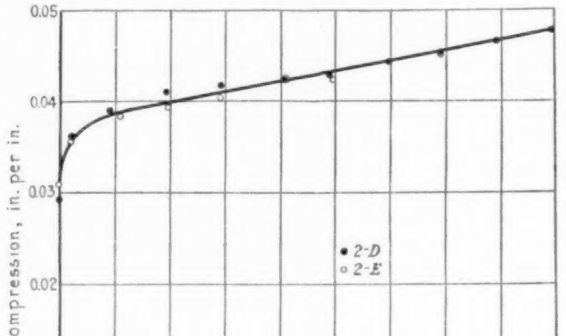



FIG. 2 COMPRESSION-TIME CURVES UNDER DEAD LOAD OF 104 LB. PER SQ. IN.

same for both specimens and was about the same on the seventh day as it was on the third day.

With material of this kind used for the support and insulation of heavy machinery that is under a constant load, it is probable that a stress about equal to the proportional limit can be safely used. Careful selection based on uniform density of relatively heavy balsa-wood blocks appears to be well worth while for this purpose.

## Discussion

W. J. KREFELD.[2] The test results given by the author indicate a variation of the proportional limit as determined by a static test from 48 to 95 lb. per sq. in. with a change in density from 5.67 to 7.68 lb. per cu. ft. This fact is of considerable importance in the use of the material as a support under heavy machinery, as has been suggested by the author, especially where the area is large, necessitating the use of a number of pieces suitably connected together. A variation such as just indicated over a large supporting area would undoubtedly result in a non-uniform bearing pressure, with probable overload of the denser material and unequal settlement of the machine.

The curve shown in Fig. 2 indicates practically a uniform rate of compressive strain under a constant static load over a period of 1 to 9 days. It is to be noted that these specimens were of comparatively small area when considering machinery supports, and no data are available concerning this rate of compressibility for wood of varying density. The average compressibility of a large area of a composite foundation bed would depend upon the relative properties of the wood used in making up the bed. Where the supporting bed is of uniform material, Fig. 2 would indicate a continued settlement and, while the machine may remain level, its alignment or grade would be changed, which would be of considerable importance in the case of shafting, bearings, etc.

All of the tests have been made under static loads. It would be interesting to determine the properties with respect to the compressibility-time relation under repeated loads, introducing the effect of vibration and impact produced in many machines with moving parts. It has been the experience in other species of wood that the resilience may ultimately be destroyed when loads slightly above the elastic range have been applied repeatedly. In order to determine the permanent supporting power of balsa wood under a vibrating machine it would be necessary to ascertain the limiting stress under which practically no further permanent sets were produced.

The writer would suggest that the author furnish data relative to the ultimate deformation under varying static and dynamic loads.

[2] Engineer of Tests, Columbia University, New York, N. Y.

H. F. HOEVEL.[3] The most important requirements of a good insulating material against the transmission of vibration of machines are permanent and sufficient elasticity. Its task is to absorb vibration by converting the energy of motion (kinetic energy) into internal strain (latent energy). An insulating material will answer these requirements all the better the more it compresses or shortens under a certain load, and the more completely and quickly it recovers and resumes its original shape after the load has been removed.

Machines, including their foundations, placed on insulating material usually exert a pressure on the material of up to 2000 lb. per sq. ft. and very rarely up to 3000 lb. per sq. ft. A material must be judged by its elasticity and insulating effect within these loads.

From the data given in Fig. 1 it appears that balsa wood compresses very little and therefore has little insulating effect under loads up to 20 lb. per sq. in., or the equivalent of 2880 lb. per sq. ft. Attention is also drawn to the statement in the report that the set after each application of load was in all cases a very appreciable part of the deformation under load and was roughly one-half of this deformation up to the proportional limit. This means that balsa wood after a downwardly directed vibration impact will recover only one-half of its compression. Consequently the energy of motion of additional downwardly directed vibration impacts will not fully be converted into internal strain by balsa wood but will pass through the insulating material and will travel into the soil as vibration. The elasticity and resilience necessary for the insulation of machines has been attained to a remarkable degree in the product known commercially as "Korfund," through the peculiar type of construction employed. It consists of strips or blocks of pure natural cork, specially selected for this purpose, carefully cut to size and bound together with an iron frame which is not quite as thick vertically as the cork. The cork used is treated by a special process to preserve the normal degree of moisture which is so vital to it.

Tests made by New York University, College of Engineering, show that it compresses readily under a pressure of about 2000 lb. per sq. ft. and that the permanent set immediately after the load has been removed is only about $1^1/_2$ per cent to 4 per cent, and even less, 5 minutes after the load has been removed.

PAUL H. BILHUBER.[4] The writer's first knowledge of the use of this wood as a packing material was its application by the Victor Talking Machine Company of small blocks glued to the insides of the cases into which machines were packed, the idea

[3] President, Korfund Co., New York, N. Y. Mem. A.S.M.E.

[4] Assistant Factory Manager, Steinway & Sons, Long Island City, N. Y. Assoc. A.S.M.E.

being that they would take a certain amount of compression, be more or less elastic, and protect the contents of the case from the shocks incident to transportation. That practice apparently was given up in favor of some more elastic material after about two years. Steinway & Sons also made similar use of it for a very short time. It seemed that when the material was compressed and dented, it did not have the elasticity the users hoped to find, and for that reason its usefulness ended. The balsa tree is of very rapid growth, therefore the texture of the wood is not uniform; it is very hard to get large pieces of uniform texture.

T. D. Perry.[5] The writer had quite an acquaintance with balsa wood just before the World War, and one of the great difficulties encountered at that time was its very great tendency to decay. It is a very soft wood, very porous, and absorbs moisture readily. The wood decays so rapidly that it has been found necessary for various applications to impregnate it with paraffin. In attempts to make the wood strong it has been compressed after impregnation, and the author has seen pieces of it compressed almost to the hardness of oak. Balsa wood did not seem to get very far then as a wood of commerce. The writer's last contact with it was in connection with life preservers. It has almost twice the buoyancy of cork, and with the paraffin impregnation has a long life. Many of the life rafts observed toward the end of the war, instead of being blown up with air or filled with pulverized cork, were made of solid pieces of this wood. The wood is so soft that one may with perfect ease drive a half-inch dowel into a block without fear of splitting or in any way damaging the wood. The writer has grave doubts as to its value as a cushion for machinery in comparison with the harder woods we are accustomed to using. Pines, spruces, and birch woods, and a number of native woods would have nearly as much elasticity as balsa wood under compression and would be easier to get and not so liable to deteriorate.

Arthur Koehler.[6] There seems to be no mention of the moisture content of the samples tested. That is very important because of its great influence on strength. A piece of spruce, for example, kiln-dried, may be four times as strong as the green wood. Anything put into machinery would be subject to high variation in this respect; in one shop it might be air dry and in another shop it would have a very high moisture content down on the floor, thereby greatly reducing the strength.

At one point in the paper the "heart of the tree" is mentioned. In the next sentence the words "specimens for lower density which generally contain heartwood" appear. Now, in all the pieces of balsa that the writer has seen there seemed to be no difference between heartwood and sapwood. They were all the same color and were uniform throughout. Perhaps the author will explain in more detail just what he means, and if he means a certain distance from the bark.

C. H. Tanger.[7] Experiments have been conducted on balsa wood as a vibration absorber underneath household refrigeration units. In order to get the proper characteristics of the wood balsa was used as a core for a laminated board, a board hard of surface being employed to distribute the weight over a large surface. The balsa-wood core was subjected to a specific-gravity test for density before laminating.

[5] Director, Woodworking Division, Bigelow Kent, Willard & Co., Inc., Boston, Mass. Mem. A.S.M.E.

[6] Forest Products Laboratory, Madison, Wis.

[7] Kelvinator Corporation, Detroit, Mich.

The refrigerator manufacturers are particularly interested in its use as an insulator. Because of its strength, a separate frame for the refrigerator is not required; the insulation and the frame are one.

C. C. Travis.[8] Balsa wood is being used with considerable success in the aircraft industry at this time, and its ability to absorb vibration and reduce noise, as well as insulate against low temperatures, would seem to indicate that this field promises much for this tropical wood. It has also found favor as a material for the manufacture of radio parts, because of its excellent acoustic properties. Another interesting use of balsa is in the construction of the new ramp alongside the Grand Central Station in New York City. The city engineers found that a layer of balsa under the pavement absorbed a large part of the vibrations that ordinarily would be transmitted into the steelwork. It is also being used as a sound deadener where a vessel is inclined to vibrate sympathetically with a machine. Oil burners have been made to operate quietly by placing them on balsa-wood bases. Its use in household refrigerating machines has already been mentioned.

The density of the wood can be controlled by proper attention at the point of origin. Balsa trees reach commercial size in six to seven years, when they attain a diameter of 22 inches and reach a height of 50 feet. At that stage the wood contains about three times its weight in water. After that time the sap starts to harden and the wood deteriorates at an increasing rate. Prior to two years ago the chief difficulty lay in this fact. In other words, the wood was cut after it had reached too advanced an age, after the sap had hardened, or was well on the way. Further, in the kiln-drying process the destructive bacteria also are killed before they have had time to attack the wood.

## Author's Closure

It is realized that the tests described in the paper are by no means exhaustive and that more tests should be made, not only of balsa wood, but also of other materials used for the same purpose. If the problem of insulating machinery so that the vibrations are not transmitted to the floor is an important one, it would be well for some committee of the Society to decide what properties of the material are important and what tests should be carried out in order to differentiate between materials.

Mr. Hoevel has pointed out that a pressure of about 20 lb. per sq. in. is usual under machine bases. The curve of Fig. 2 represents conditions much more severe, and it is probable that there would be little compression with time for a load of 20 lb. per sq. in.

Balsa wood has a modulus of elasticity very much smaller than that of any common wood, and therefore would have a proportionately greater insulating effect, even at 20 lb. per sq. in.

The specimens were very dry when tested. No measurements were made to determine the moisture content, but the material was in the laboratory for several weeks before test. It is recognized that the moisture content would probably affect the properties of any insulating material.

Some of the specimens contained the pith at the center of the tree, and this part was referred to as "heartwood." The annular rings were much farther apart near this center and the density less. The appearance of the piece was similar to that of any softwood cut across the grain and was not uniform throughout. Specimens 2-D and 2-E were selected so as to have the same density. Fig. 2 shows the remarkable similarity in strength properties of these pieces having the same density.

[8] The Travis-Quaintance Co., Grand Rapids, Mich.

# Engineering Characteristics of Plywood[1]

By THOMAS D. PERRY,[2] BOSTON, MASS.

PLYWOOD is a recently adopted name for the product of an age-old art. The story of the early art has been found cut in stone in the days of the Pharaoh of the Exodus. Furniture recently discovered in the tomb of King Tut gives evidence of wonderful skill in veneering, and veneering is an early type of plywood.

Fundamentally, wood consists of bundles of slender fibers growing vertically in trees, and most fibers are substantially parallel to each other. A few fibers occur in radial directions in certain species, of which the quartered-oak "figure" is a well-known example. Wood splits with relative ease along the grain, but is most difficult to cut across the grain unless a swath or saw kerf is removed with a saw.

While much attention has been given to determining the ultimate strength as well as reasonable working limits of many materials used in the engineering trades, wood is not among those adequately demonstrated. Wood joists and timbers have had considerable testing, but smaller units have had almost no attention as to strength limits and ranges. Hence the need for this consideration of plywood possibilities.

Plywood is one kind of laminated or compound wood and consists of several sheets (plies or folds) of thin wood (or veneer) glued together, either in flat or curved shapes. Usually, but not necessarily, the adjacent layers or sheets of wood have their respective fibers or grain at right angles to each other. Obviously, internal stresses and strains are balanced in such construction, resulting in permanence of dimension and shape.

The strength increment of plywood over solid wood comes from this skilful combining of wood fibers at suitable transverse angles in proper ratios of thickness and with sufficient glue of a character suited to the ultimate utility of the plywood.

## Kinds of Veneer Used in Plywood

The thin sheets of wood or veneer used in assembling into plywood are manufactured in four ways, viz.:

- *Rotary cut* from logs revolved in a veneer lathe
- *Slice cut* from logs or flitches moved angularly against a slicing knife
- *Sawed* on a segment saw
- *Half-round cut* from flitches mounted on a wide-swing or eccentric lathe.

If these are to be arranged according to volume of production, rotary cutting (Fig. 1) will easily stand at the head of the list (92 per cent), since most plain veneers are so made as well as some figured woods. The veneer is lathe cut and spirally unrolled from the log somewhat as paper is unwound from a roll. Logs never grow perfectly symmetrical, so that a sheet of rotary veneer may show parts of several growth rings.

The straightening out or flattening of rotary-cut veneer is shown (greatly exaggerated) in Fig. 2. While logs are cooked to soften the texture before rotary cutting, yet some stretching on the concave side is essential to allow flattening. In veneer $^1/_{16}$ in. thick (and less) these cutting checks are negligible and commercially and scientifically unimportant, but in veneer $^1/_8$ and $^3/_{16}$ in. thick their presence must be recognized as an element of wood strength.

*Slicing* veneer (Fig. 3) is the standard cutting practice for mahogany and most other figured woods. The sheets of veneer are sheared from the flat surface of a hewn log or sawed flitch. These cuts extend across many or few growth rings, according to the distance from the center of the log. Sliced veneer is sometimes cut radially (quartered), but is usually cut across.

*Sawing* (Fig. 4) veneer with segment saws, although the earliest modern method, is chiefly used for quartered oak. The saw-kerf waste is usually equivalent to the thickness converted into veneer, hence the method is not economical and is applied only to woods and products that cannot be cut advantageously by any other method. About 5 per cent of all veneer is sawed.

*Half-round cutting* (Fig. 5) is done on a lathe by the use of a "stay log," an eccentric device that permits rotary cutting in a wider sweep, or with greater diameter, than when the log is mounted on the usual lathe centers. Semi-circular sheets, instead of being cut from the outside of the log toward the heart, may be cut from the heart toward the outside.

## Glues Used in Plywood

*Animal Glue.* This standard and recognized wood adhesive is sold in many grades and is made from bones and hides. It is prepared for use by dissolving it in water under moderate temperatures (140 deg. fahr.). It penetrates wood well, but is best applied in a hot room. It is soluble in water.

*Vegetable Glue.* Vegetable glue is made of a starch flour, usually tapioca flour or cassava, with water and caustic. It is prepared in a mechanical mixer by vigorous beating and cooked for some time. While in the early stages of preparation it appears to be a milky water, it later becomes a viscous fluid, rather thicker than syrup. It is economical in cost, principally used for plywood, of abundant strength, easy to use, but not waterproof.

*Casein Glue.* Casein glue is the resul. of vigorously mixing, without heat, casein (from self-soured or acid-soured milk), caustic, water, and hydrated lime. The resulting glue is a thick milky liquid, not "tacky" in its fluid form, but producing a highly water-resistant glue when dry, practically non-soluble in water. Hence it is usually specified for plywood for vessels, aircraft, and other exposed locations.

*Albumin Glue.* This consists chiefly of dried blood, mixed cold and rather gently. When applied to veneer, not over $^1/_{16}$ in. thick, it adheres due to the coagulation of the glue under action of steam-heated platens. This coagulation takes place from 175 to 200 deg. fahr., and veneer thicker than $^1/_{16}$ in. is likely to discolor from heat during coagulation. Each layer of veneer applied requires separate coagulation. This glue when property coagulated is practically waterproof and hence its use is permitted under the most rigid waterproof specifications.

*Silicate Glue.* Silicate glue consists of silicate of soda or liquid glass and is a low-priced glue used in box shooks and less costly plywood products.

There are various other less frequently used wood glues: liquid glues from fish bladders, soy-bean glue, potato-starch glues, and others, but their use in plywood is unimportant.

[1] Portions of the material herein presented were prepared by the author and published in "Veneers and Plywood" by Knight and Wulpi, Ronald Press, 1927, and are used here by permission.

[2] Director, Woodworking Division, Bigelow, Kent, Willard & Co., Inc. Mem. A.S.M.E.

Presented at the Third National Meeting of the A.S.M.E. Wood Industries Division, Grand Rapids, Mich., November 26 and 27, 1928.

### Plywood Assembly Procedure

Plywood glues are usually mixed mechanically and spread by revolving spreaders. The assembled plywood must go under a hydraulic press (at approximately 75 lb. per sq. in. pressure) before the initial set of the glue has begun, and remain under pressure or in clamps for not less than four hours. It is then dried, cut to size, and sanded.

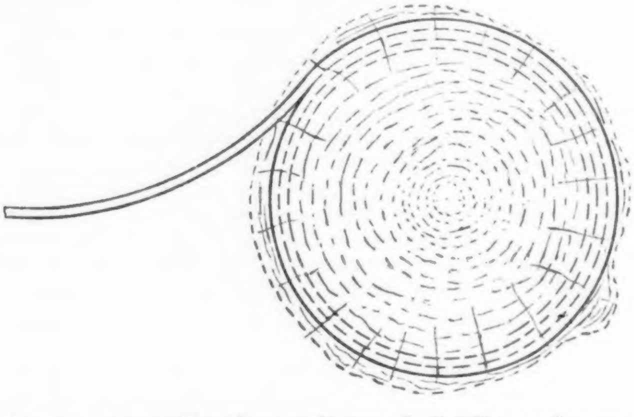


Fig. 1 Showing How Rotary Veneer Is Cut From a Log or Bolt After the Uneven Exterior Has Been Cut Away. Note the Probability of Irregular Figure, With No Two Sheets Alike

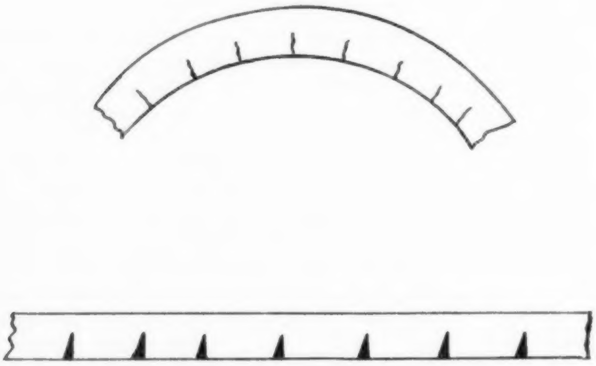


Fig. 2 Showing, Greatly Exaggerated, Why Rotary-Cut Veneer When Flattened From Its Original Curved Form Will Exhibit Cutting Checks Where the Fibers Have Been Forced Apart In the Flattening Process

### Waterproofness as Applied to Plywood

There is as yet no simple and effective process of rendering wood entirely waterproof. At the present time, certain glues are more waterproof than the wood they join together. In other words, the immersion of plywood in water will not soften or dissolve a properly made and applied casein or blood albumin glue. Such immersion, however, will eventually penetrate the openings of the wood sufficiently to shrink or swell the wood fibers enough either to tear them apart, or to tear them away from the glue. When immunity from such water saturation of wood becomes practicable, the opportunities for the development of plywood along mechanical lines will be almost unlimited.

### The Use of Plywood in Furniture

The original use of veneer in furniture and interior construction was to supply a base or inert foundation on which to mount an extremely fragile or intricately patterned thin veneer. While economically sound in principle and scientifically correct in result, this utilization gave rise to the erroneous opinion, most widely held, that veneer is used to cover up an inferior product, and therefore is superficial, and represents neither a high grade of craftmanship nor a substantial product.

Furniture manufacturers have continued this use of veneer because of the fundamental correctness of the policy from every viewpoint, but popular opinion is still reluctant to accept a mahogany-plywood table top as even the equivalent of a solid-mahogany top. The facts are, as developed from the author's twenty-five year intimate contact with wood construction, that a well-made plywood table top is mechanically and artistically superior to one of solid wood.

The original method of applying a thin veneer by hand on a white-pine core or base, with face and core grain parallel and without a right-angled cross veneer between, has been supplanted by the modern plywood construction shown on the left half of Fig. 6. In this the transverse stresses are carried by the crossed grain of the adjacent layers, and the plywood product is therefore obviously stronger, stiffer, and less likely to warp than solid wood.

In addition to this use of 5-ply in furniture, chiefly designed to furnish a substantial base for a fragile veneer as well as for matched and intricately patterned veneer effects, considerable 3-ply is used in the plain woods where strength and lightness are essential. This is shown in the right half of Fig. 6.

In the making of furniture and allied products, however, neither solid wood nor plywood is subject to anything like maximum stresses, and while the strength increment of plywood is of service, the laminations are usually to preserve the figured face of the veneer.

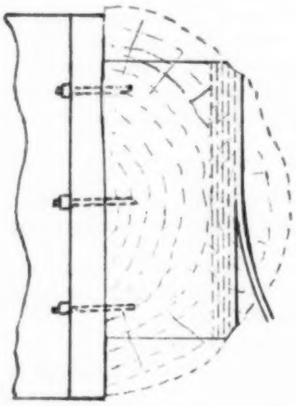


Fig. 3 Showing How Sheets Are Sliced From a Hewn (or Sawed) Log, Sometimes Halved and Quartered. Note the Probability of Almost Identical Figure on Adjacent Sheets

### Possible Strength Qualities of Plywood

The tremendous potential field for the use of plywood as a wood construction of maximum strength consistent with minimum thickness and weight, was realized only in meager outline during the development of airplanes during the war. From time to time the vigorous promotion of sheet and tubular metals has threatened to outdistance plywood, but still plywood remains as a product of remarkable utility in a wide diversity of products required by engineers.

### Analysis of Plywood Characteristics

Plywood, or laminated wood glued up with thin sheets of veneer

alternating in direction of grain, is stronger than an equal thickness of ordinary solid wood for several reasons, among which the following clearly come within the engineering field.

*Tension and Compression.* Wood will resist a much greater tension and a much greater compression per unit of sectional area in the direction of the grain (the fibers) than it does at right angles thereto.

*Resistance to Shear.* This same difference occurs in resisting shear, or the force necessary to make one part slide by another in a given plane. In shear, however, the wood will resist a greater force along a plane perpendicular to the grain than along a plane parallel to it. Furthermore, in a plane parallel to the grain it has higher resistance to shear sidewise, at 90 deg. to the grain, than along the grain. In other words, the resistance of wood to shearing is less along the grain than in any other direction.

*Bending.* There can be no bending without the development of tension and compression. Wood has a much greater resistance to bending in the direction of the fibers or lengthwise of the grain than sidewise, or at 90 deg. to the grain. If, therefore, it were possible to have an ideal form of wood construction with the fibers running in both directions, it would provide an equal strength in every direction so far as tension and compression are concerned.

Furthermore, the bending of an object of uniform thickness produces the maximum tension and compression per unit of sectional area at the outer and opposite surfaces. That is, when an object is bent there is a pulling apart or tension on the convex side and a pressing together or compression on the concave side. Somewhere between is a point at which there is neither pulling nor pressing, which is called the neutral axis. As the tension and compression are zero at this neutral axis and maximum at the opposite surfaces, it can be easily seen that a relatively small thickness at each surface supplies the great bulk of the tension and compression which together constitute the resistance to bending. That is the chief reason why a thickness of veneer, perhaps one-sixth of the total thickness of a board, placed with parallel grain on top and bottom of an inert substance, will supply nearly all of the tensile and compressive strength supplied by a solid board of equal thickness.

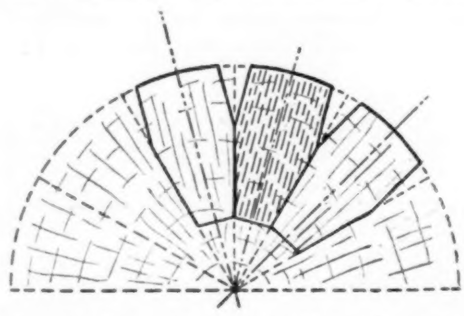


FIG. 4 QUARTER-SAWED VENEER IS MADE FROM SEGMENTAL FLITCHES, AS THE SECTIONS ARE CALLED, AND OBVIOUSLY ONLY ONE SHEET OF VENEER IN EACH FLITCH IS GENUINELY QUARTERED. THE REMAINING SHEETS HAVE ENOUGH FIGURE TO GRADE AS "QUARTERED"

*Cross-Laminations Distribute the Load.* When such a laminated board is made with similar cross-layers directly under these outer layers, the board will have a similar resistance to bending in the opposite direction, but not so great because the layers are nearer together and have the effect of a board of so much less thickness. If, however, the length of span sidewise is reduced so that its square is in the same proportion to the square of the length of the main span as the relative distance between the centers of the inner and outer veneers, approximately, the board will have practically equal resistance to bending (or equal strength) in both directions, other things being equal. The result is that the load will be distributed when supported continuously on four sides, and therefore require much less thickness in plywood than in solid wood, depending on the arrangement of the veneers and the relative length of span in each direction.

There can be no resistance to bending, even when the resistances to tension and compression are supplied, unless there is also provided a resistance to longitudinal shear. Several thin layers just placed together (without glue) will offer little resistance to bending and carry but a relatively small load because they bend independently of each other and have no bond to unite them so as to resist sliding upon each other in the direction of the span, and thus they fail to bring into use the full strength of the outer layers. This resistance is known as longitudinal shear. It is necessary, therefore, that the successive layers should be firmly bonded together into plywood by means of glue.

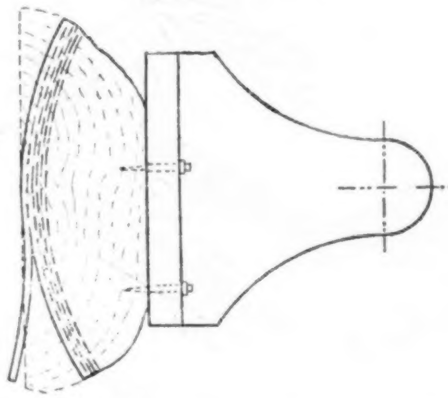


FIG. 5 ONE METHOD OF CUTTING "HALF ROUND," SHOWING HOW A CROTCH CAN BE HALVED (ON A SAW) AND CUT INTO SIMILAR ADJACENT SHEETS TO REVEAL THE BEAUTIES OF HEART-CROTCH FIGURE

Since wood, as stated before, has a greater resistance to shear sidewise than along the grain, and because this shear in bending acts in the direction of the span parallel with the top and bottom fibers, it is perfectly apparent that layers of veneer placed crosswise in plywood increase this resistance to this longitudinal shear. As wood is likely to fail as much in longitudinal shear as in tension and compression, the alternate layers of cross-veneers in plywood materially increase the ultimate resistance to bending in both directions.

*Combined Resistance.* In effect therefore, when the grains of the alternate layers are, by construction, at right angles to each other as in plywood, one layer supplies a maximum resistance either to tension or compression, and the next to longitudinal shear in one direction. Adjacent layers act with a maximum resistance in the reverse direction.

As a matter of strength of materials and of mechanics alone, the use of plywood or laminated veneers does not increase the resistance to vertical shear. Vertical shear is the tendency or force of a load on a span, acting in a direction opposite to the support, to shear across the object. When a piece is supported on four sides, however, the load is divided and passes to each pair of supports, and in this way reduces the effect of vertical shear at any cross-section.

*Influence of Glue.* The use of glue, however, undoubtedly helps this shear resistance, but as wood does not as readily show

failure from vertical shear as from the other forms of stress, transverse shear does not enter largely as a factor into this case.

The effect of using glue in bonding the alternate layers into plywood is an important factor. The application of glue to wood acts not only as a binder between surfaces, but in so far as it penetrates the wood fibers, it acts as a binder between the fibers themselves. It also provides this resistance to longitudinal

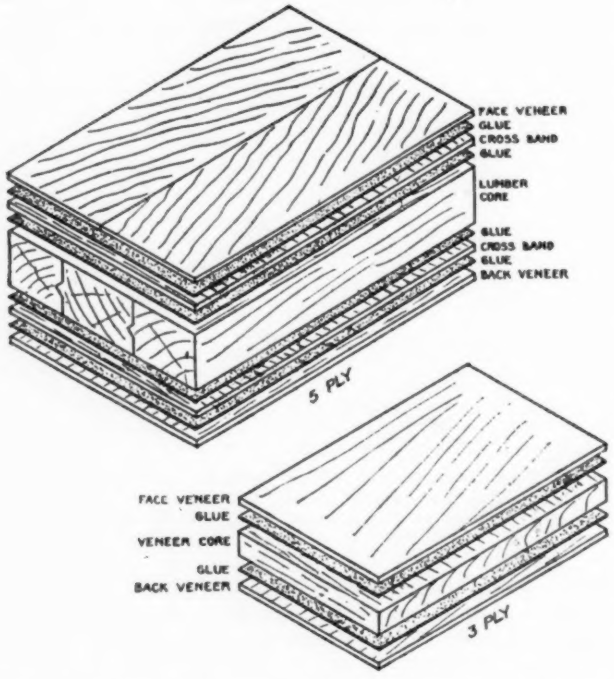



FIG. 6 SHOWING CONSTRUCTION OF 5-PLY AND OF 3-PLY, THE STRATA BEING SEPARATED TO INDICATE STRUCTURAL FEATURES, AND GIVING AN IDEA OF HOW INTERNAL STRESSES IN ALL STRATA ARE EQUALIZED IN MODERN FURNITURE DESIGN

shear, depending upon the quality of the layers, and thus increases the total resistance to all forms of stress. It does this because good glue generally is stronger than the element of adhesion that nature provides between wood fibers.

As the penetration of the glue into the wood is not great, its influence on the ultimate strength of thick layers, other than at their immediate junction, is not appreciable. In the case of such plywood construction as has been described, however, particularly inner veneer layers glued on both sides and treated under heat and pressure, the penetration is an appreciable proportion of the lamination and adds to the aggregate "built-up" plywood an appreciable resistance to all forms of stress.

Cross-veneering or cross-layers in plywood also have a tendency to counterbalance stresses and uneven shrinkage in the wood, and thereby prevent the manifestation of the internal stresses that are an element of weakness in solid wood.

*Summary.* The foregoing may be summed up in the statement that plywood made of relatively thin layers of veneer, with the direction of grain alternating, owes its valuable and economic qualities to the fact that this arrangement, properly applied, utilizes all of the strength of the wood to the best possible advantage in resisting the several kinds of stress and deformation that occur in all forms of bending and torsion.

Government tests at the Forest Products Laboratory have proved that plywood at its best is stronger per pound of weight than solid steel.

## APPLICATIONS OF PLYWOOD TO THE ENGINEERING TRADES

This multiplication of wood strength secured by the laminations of veneers into plywood opens a new field of great usefulness that has scarcely been seriously considered as yet.

*Shipbuilding.* Many are the places on shipboard, particularly passenger ships, where the sturdy strength and relative lightness of plywood together with its economical installation in large sheets make it the ideal material for bulkheads or partitions. It can be curved as much as desired when glued and can be slightly bent and twisted in installation. Shrinking and swelling are reduced to a negligible minimum by the balanced stresses in the alternately crossed plies. It is dust- and light-proof and more sound-resistant than solid wood or metal. Plywood bulkheads are usually 5-ply or 7-ply, and are cut from sheets approximately 48 in. by 96 in. long.

*Automotive Construction.* Disk automobile wheels with a web of plywood instead of metal will greatly reduce wheel weights and are already in the experimental stage, giving promise of success. Laminated side frames afford easy riding qualities to one popular make of car. Plywood bumper bars afford resilient and elastic properties and do not so easily mark and damage the opposing car as do metal bumpers. Bus and delivery body sides and tops are formed in plywood, resulting in a maximum of strength with a minimum of weight. Where larger than standard sizes are required, joints can be "scarfed" and glued together, resulting in strength equivalent to that of the original sheet.

*Airplane Requirements.* During the war, plywood of veneers proved to be light and strong, and was largely used for fuselage and wing construction. Propellers were made of another type of plywood which might be described as "laminated lumber." The speed of a propeller tip is enormous, and lightness in weight is essential to reduce centrifugal force and the resulting strains and stresses. When this country seriously undertakes the development of a protective as well as a commercial air policy, the

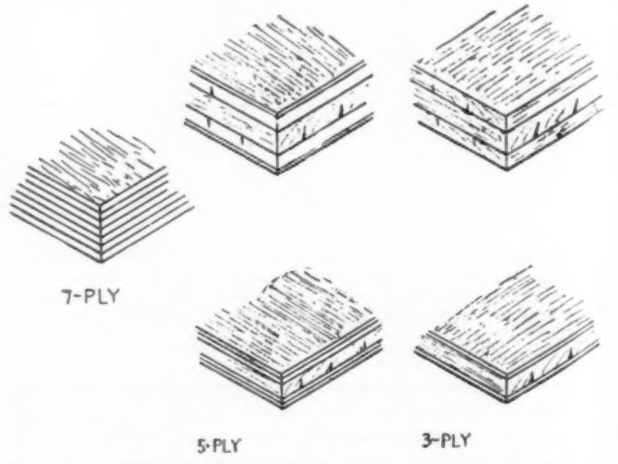



FIG. 7 SHOWING VARIOUS TYPES OF PLYWOOD CONSTRUCTION WITH DIFFERENT PLIES AND CORES

opportunity for the use of plywood in airplanes will be greatly enhanced.

*Plywood Containers.* The plywood packing case is an example of "equal-thickness ply" construction made of three thicknesses of $^1/_{20}$- or $^1/_{16}$-in. rotary-cut veneer. After gluing and cutting these sheet shooks to size they are stiffened by means of wooden strips nailed on all four edges. These reinforced sheets are set up in a case, and when so set up may be used for a wide variety of merchandise packing.

TABLE 1 OVEN-DRY WEIGHTS OF VENEER OF VARIOUS SPECIES AND THICKNESSES

(In ounces per square foot of 1-ply.)

| Species | Specific gravity based on oven-dry weight and air-dry volume | Air-dry moisture content, per cent | Veneer Thickness in Inches 1/100 | 1/80 | 1/64 | 1/60 | 1/55 | 1/48 | 1/40 | 1/32 | 1/28 | 1/24 | 1/20 | 1/16 | 1/12 | 1/10 | 1/8 | 1/6 | 3/16 | 1/4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ash, black | 0.50 | 10.4 | 0.42 | 0.52 | 0.65 | 0.69 | 0.76 | 0.87 | 1.04 | 1.30 | 1.49 | 1.74 | 2.08 | 2.60 | 3.47 | 4.16 | 5.20 | 6.94 | 7.81 | 10.41 |
| Ash, commercial white | 0.58 | 8.9 | 0.48 | 0.60 | 0.75 | 0.80 | 0.88 | 1.00 | 1.21 | 1.51 | 1.72 | 2.01 | 2.41 | 3.02 | 4.02 | 4.82 | 6.04 | 8.05 | 9.05 | 12.06 |
| Basswood | 0.38 | 8.4 | 0.32 | 0.40 | 0.49 | 0.53 | 0.58 | 0.66 | 0.79 | 0.99 | 1.13 | 1.32 | 1.58 | 1.98 | 2.64 | 3.16 | 3.96 | 5.28 | 5.94 | 7.92 |
| Beech | 0.63 | 11.2 | 0.52 | 0.66 | 0.82 | 0.87 | 0.95 | 1.09 | 1.31 | 1.64 | 1.87 | 2.19 | 2.62 | 3.28 | 4.37 | 5.24 | 6.56 | 8.74 | 9.84 | 13.12 |
| Birch, yellow | 0.63 | 9.6 | 0.52 | 0.66 | 0.82 | 0.87 | 0.95 | 1.09 | 1.31 | 1.64 | 1.87 | 2.19 | 2.62 | 3.28 | 4.37 | 5.24 | 6.56 | 8.74 | 9.84 | 13.12 |
| Butternut | 0.39 | 7.6 | 0.32 | 0.41 | 0.51 | 0.54 | 0.59 | 0.68 | 0.81 | 1.02 | 1.16 | 1.35 | 1.62 | 2.03 | 2.71 | 3.25 | 4.06 | 5.42 | 6.09 | 8.12 |
| Cedar, Spanish | 0.37 | 7.2 | 0.31 | 0.38 | 0.48 | 0.51 | 0.56 | 0.64 | 0.77 | 0.96 | 1.10 | 1.28 | 1.54 | 1.92 | 2.56 | 3.08 | 3.85 | 5.13 | 5.77 | 7.70 |
| Cherry, black | 0.51 | 9.2 | 0.42 | 0.53 | 0.66 | 0.71 | 0.77 | 0.88 | 1.06 | 1.33 | 1.52 | 1.77 | 2.12 | 2.65 | 3.54 | 4.25 | 5.31 | 7.08 | 7.97 | 10.62 |
| Chestnut | 0.44 | 8.6 | 0.37 | 0.46 | 0.57 | 0.61 | 0.67 | 0.76 | 0.92 | 1.14 | 1.31 | 1.52 | 1.83 | 2.29 | 3.05 | 3.67 | 4.58 | 6.10 | 6.87 | 9.16 |
| Cottonwood (common) | 0.43 | 4.7 | 0.36 | 0.45 | 0.56 | 0.60 | 0.65 | 0.75 | 0.90 | 1.12 | 1.28 | 1.49 | 1.79 | 2.24 | 2.98 | 3.58 | 4.47 | 5.97 | 6.71 | 8.96 |
| Cypress bald | 0.44 | 9.0 | 0.37 | 0.46 | 0.57 | 0.61 | 0.67 | 0.76 | 0.92 | 1.14 | 1.31 | 1.52 | 1.83 | 2.29 | 3.05 | 3.67 | 4.58 | 6.10 | 6.86 | 9.16 |
| Douglas fir (Washington and Oregon) | 0.51 | 6.2 | 0.42 | 0.53 | 0.66 | 0.71 | 0.77 | 0.88 | 1.06 | 1.33 | 1.51 | 1.77 | 2.12 | 2.65 | 3.53 | 4.24 | 5.30 | 7.08 | 7.96 | 10.6 |
| Douglas fir (Montana and Wyoming) | 0.44 | 9.4 | 0.37 | 0.46 | 0.57 | 0.61 | 0.67 | 0.76 | 0.92 | 1.15 | 1.31 | 1.53 | 1.83 | 2.29 | 3.05 | 3.66 | 4.58 | 6.10 | 6.87 | 9.16 |
| Elm, white | 0.51 | 8.8 | 0.42 | 0.53 | 0.66 | 0.71 | 0.77 | 0.88 | 1.06 | 1.33 | 1.52 | 1.77 | 2.12 | 2.65 | 3.54 | 4.25 | 5.31 | 7.08 | 7.97 | 10.62 |
| Gum, black | 0.52 | 7.2 | 0.43 | 0.54 | 0.68 | 0.72 | 0.79 | 0.90 | 1.08 | 1.35 | 1.55 | 1.80 | 2.17 | 2.71 | 3.61 | 4.33 | 5.42 | 7.32 | 8.12 | 10.82 |
| Gum, cotton | 0.52 | 6.1 | 0.43 | 0.54 | 0.68 | 0.72 | 0.79 | 0.90 | 1.08 | 1.35 | 1.55 | 1.80 | 2.17 | 2.71 | 3.61 | 4.33 | 5.42 | 7.32 | 8.12 | 10.82 |
| Gum, red | 0.49 | 11.3 | 0.41 | 0.51 | 0.64 | 0.68 | 0.74 | 0.85 | 1.02 | 1.28 | 1.46 | 1.70 | 2.04 | 2.55 | 3.40 | 4.08 | 5.10 | 6.80 | 7.66 | 10.20 |
| Hackberry | 0.54 | 9.2 | 0.45 | 0.56 | 0.70 | 0.75 | 0.82 | 0.94 | 1.12 | 1.40 | 1.61 | 1.87 | 2.25 | 2.81 | 3.75 | 4.49 | 5.63 | 7.50 | 8.44 | 11.24 |
| Hemlock, western | 0.42 | 8.6 | 0.35 | 0.44 | 0.55 | 0.58 | 0.64 | 0.73 | 0.87 | 1.09 | 1.25 | 1.46 | 1.75 | 2.18 | 2.91 | 3.50 | 4.37 | 5.83 | 6.56 | 8.74 |
| Magnolia (evergreen) | 0.51 | 8.8 | 0.42 | 0.53 | 0.66 | 0.71 | 0.77 | 0.88 | 1.06 | 1.33 | 1.51 | 1.77 | 2.12 | 2.65 | 3.53 | 4.24 | 5.30 | 7.08 | 7.96 | 10.6 |
| Mahogany, Central American | 0.49 | 7.9 | 0.41 | 0.51 | 0.65 | 0.68 | 0.75 | 0.85 | 1.02 | 1.28 | 1.46 | 1.70 | 2.04 | 2.55 | 3.50 | 4.08 | 5.10 | 6.80 | 7.66 | 10.20 |
| Mahogany, African | 0.46 | 8.0 | 0.38 | 0.48 | 0.60 | 0.64 | 0.70 | 0.80 | 0.96 | 1.19 | 1.37 | 1.59 | 1.91 | 2.39 | 3.19 | 3.83 | 4.78 | 6.38 | 7.17 | 9.57 |
| Maple, silver | 0.48 | 8.2 | 0.40 | 0.50 | 0.62 | 0.67 | 0.73 | 0.83 | 1.00 | 1.25 | 1.43 | 1.67 | 2.00 | 2.50 | 3.33 | 4.00 | 5.00 | 6.66 | 7.50 | 7.00 |
| Maple, sugar | 0.62 | 10.5 | 0.52 | 0.65 | 0.81 | 0.86 | 0.94 | 1.08 | 1.29 | 1.61 | 1.85 | 2.15 | 2.58 | 3.23 | 4.30 | 5.16 | 6.46 | 8.60 | 9.69 | 12.91 |
| Oak, commercial red | 0.64 | 10.7 | 0.53 | 0.67 | 0.83 | 0.89 | 0.97 | 1.11 | 1.33 | 1.66 | 1.90 | 2.22 | 2.66 | 3.33 | 4.44 | 5.32 | 6.66 | 8.88 | 9.99 | 13.3 |
| Oak, commercial white | 0.68 | 11.0 | 0.57 | 0.71 | 0.88 | 0.94 | 1.03 | 1.18 | 1.41 | 1.77 | 2.02 | 2.36 | 2.83 | 3.54 | 4.72 | 5.66 | 7.08 | 9.43 | 10.61 | 14.1 |
| Pine, longleaf | 0.66 | 9.2 | 0.55 | 0.69 | 0.86 | 0.92 | 1.00 | 1.15 | 1.37 | 1.72 | 1.96 | 2.29 | 2.75 | 3.44 | 4.58 | 5.50 | 6.88 | 9.16 | 10.32 | 13.75 |
| Pine, sugar | 0.37 | 11.4 | 0.31 | 0.39 | 0.48 | 0.51 | 0.56 | 0.64 | 0.77 | 0.96 | 1.10 | 1.28 | 1.54 | 1.93 | 2.57 | 3.08 | 3.85 | 5.14 | 5.78 | 7.70 |
| Pine, shortleaf | 0.54 | 11.0 | 0.45 | 0.56 | 0.70 | 0.75 | 0.82 | 0.94 | 1.12 | 1.40 | 1.60 | 1.87 | 2.25 | 2.81 | 3.74 | 4.49 | 5.62 | 7.49 | 8.43 | 11.2 |
| Pine, western yellow | 0.41 | 10.8 | 0.34 | 0.43 | 0.53 | 0.57 | 0.62 | 0.71 | 0.85 | 1.07 | 1.22 | 1.42 | 1.71 | 2.13 | 2.84 | 3.41 | 4.27 | 5.69 | 6.40 | 8.54 |
| Pine, white | 0.39 | 9.9 | 0.33 | 0.41 | 0.51 | 0.54 | 0.59 | 0.68 | 0.81 | 1.02 | 1.16 | 1.35 | 1.62 | 2.03 | 2.71 | 3.25 | 4.06 | 5.42 | 6.09 | 8.12 |
| Poplar, yellow | 0.41 | 6.1 | 0.34 | 0.43 | 0.53 | 0.57 | 0.62 | 0.71 | 0.85 | 1.07 | 1.22 | 1.42 | 1.71 | 2.13 | 2.84 | 3.41 | 4.27 | 5.69 | 6.40 | 8.54 |
| Spruce, Sitka | 0.38 | 8.9 | 0.32 | 0.40 | 0.49 | 0.53 | 0.58 | 0.66 | 0.79 | 0.99 | 1.13 | 1.32 | 1.58 | 1.98 | 2.64 | 3.16 | 3.96 | 5.28 | 5.94 | 7.94 |
| Sycamore | 0.50 | 9.2 | 0.42 | 0.52 | 0.65 | 0.69 | 0.76 | 0.87 | 1.04 | 1.30 | 1.49 | 1.73 | 2.08 | 2.60 | 3.47 | 4.16 | 5.20 | 6.94 | 7.82 | 10.41 |
| Tanguile (Philippine mahogany) | 0.54 | 11.8 | 0.45 | 0.56 | 0.70 | 0.75 | 0.82 | 0.94 | 1.12 | 1.40 | 1.60 | 1.87 | 2.25 | 2.81 | 3.74 | 4.49 | 5.62 | 7.49 | 8.42 | 11.20 |
| Walnut, black | 0.57 | 4.8 | 0.47 | 0.59 | 0.74 | 0.79 | 0.86 | 0.99 | 1.19 | 1.48 | 1.70 | 1.98 | 2.37 | 2.97 | 3.96 | 4.75 | 5.94 | 7.92 | 8.91 | 11.87 |

Weight of glue per square foot of single glue line: blood albumin, about 0.3 oz.; casein, about 0.4 oz.

The plywood shooks weigh less than half as much as lumber box shooks and are tougher and stronger in service. Plywood packing cases are frequently used to protect plywood furniture from injury during shipping.

*Small Formed Boxes.* A process has recently been perfected in Europe in which veneer is cut $^1/_{100}$ in. thick and glued into 3-ply, resulting in $^1/_{32}$-in. plywood. This plywood can be formed in dies and cauls, after the glue is dried, just as pasteboard and thin metal are stamped. It is used for small boxes for cigarettes, cosmetics, and the like. This material as now made has a much wider manufacturing application.

*Interior Fitments.* Plywood is the only form of wood that can be used for large paneling without shrinking or swelling appreciably. Both flat shapes and curved ones can be used. This constructional utilization of plywood has suffered serious neglect.

Flush plywood doors offer an attractive and sanitary type of door for hospitals and public buildings. Plywood doors are more free from temperature and climatic change than any other type of door. Plywood doors can be interlined with asbestos or metal for fire-resistant or X-ray-proof purposes without detracting from their exterior appearance.

### Explanation of Table 1

Table 1 gives the approximate weight of individual sheets of veneer in ounces per square foot, making possible the computation of the weight of plywood built up of any combination of thicknesses and veneer species listed and of any number of plies. The approximate weights of two common water-resistant plywood glues in ounces per square foot of glued surface are also given.

It should be remembered that the weight of woods is quite variable, and that large differences from the figures are to be expected, particularly with small quantities of material.

*Example:* To get the weight of a square foot of 5-plywood consisting of 1-ply of $^1/_{12}$-in. basswood, 2 plies of $^1/_{16}$-in. basswood, and 2 plies of $^1/_{20}$-in. yellow birch for faces, at 12 per cent moisture, glued with casein glue:

$$\text{Weight} = [(1 \times 2.64) + (2 \times 1.98) + (2 \times 2.62)]\ 1.12 + (4 \times 0.4) = 14.9 \text{ oz.}$$

The example above is slightly in error through neglecting the change in volume between the moisture content at 12 per cent and the moisture listed in the table.

TABLE 2 STRENGTH OF VARIOUS SPECIES OF 3-PLY PANELS

(All plies in any one panel were of the same thickness and of the same species—grain of successive plies at right angles. In most cases eight thicknesses of plywood, ranging from $^3/_{20}$ in. to $^3/_4$ in. were tested.)

| Species | Average specific gravity of plywood based on oven-dry weight and volume at test | Average moisture, per cent | Column bending: Column-bending modulus: Parallel[1]: No. of tests | Lb. per sq. in. | Perpendicular[1]: No. of tests | Lb. per sq. in. | Modulus of elasticity: Parallel[1]: 1000 lb. per sq. in. | Perpendicular[1]: 1000 lb. per sq. in. | Tensile Test: Parallel[1]: No. of tests | Lb. per sq. in. | Perpendicular[1]: No. of tests | Lb. per sq. in. | Splitting resistance: No. of tests | Per cent of birch[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ash, black | 0.49 | 9.1 | 120 | 7,760 | 120 | 1770 | 1070 | 96 | 120 | 6,180 | 120 | 3940 | 240 | 3 |
| Ash, commercial white | 0.60 | 10.2 | 200 | 9,930 | 200 | 2620 | 1420 | 143 | 200 | 6,510 | 200 | 4350 | 400 | 71 |
| Basswood | 0.42 | 9.2 | 200 | 7,120 | 200 | 1670 | 1210 | 85 | 200 | 6,880 | 200 | 4300 | 400 | 63 |
| Beech | 0.67 | 8.6 | 120 | 15,390 | 120 | 2950 | 2150 | 167 | 120 | 13,000 | 120 | 7290 | 240 | 94 |
| Birch, yellow | 0.67 | 8.5 | 195 | 16,000 | 200 | 3200 | 2260 | 197 | 200 | 13,210 | 200 | 7700 | 400 | 100 |
| Cedar, Spanish | 0.41 | 13.3 | 115 | 6,460 | 115 | 1480 | 1030 | 84 | 115 | 5,200 | 115 | 3340 | 230 | 60 |
| Cherry[3] | 0.56 | 9.1 | 115 | 12,260 | 115 | 2620 | 1630 | 152 | 115 | 8,460 | 115 | 5920 | 230 | 80 |
| Chestnut | 0.43 | 11.7 | 40 | 5,160 | 40 | 1110 | 740 | 75 | 40 | 4,430 | 40 | 2600 | 80 | 74 |
| Cottonwood[4] | 0.46 | 8.8 | 120 | 8,460 | 120 | 1870 | 1440 | 109 | 120 | 7,280 | 120 | 4240 | 240 | 85 |
| Cypress, bald | 0.45 | 8.0 | 113 | 8,890 | 113 | 1850 | 1220 | 95 | 113 | 6,160 | 113 | 3980 | 148 | 49 |
| Douglas fir[5] | 0.48 | 8.6 | 176 | 9,340 | 200 | 1940 | 1530 | 126 | 200 | 6,188 | 200 | 3910 | 374 | 63 |
| Elm, cork | 0.62 | 9.4 | 65 | 12,710 | 65 | 2500 | 1980 | 136 | 65 | 8,440 | 65 | 5500 | 130 | 99 |
| Elm, white | 0.52 | 8.9 | 160 | 8,680 | 160 | 1970 | 1220 | 109 | 160 | 5,860 | 160 | 3990 | 320 | 75 |
| Fir, true[6] | 0.40 | 8.5 | 24 | 9,200 | 24 | 1811 | 1580 | 100 | 24 | 5,670 | 24 | 3770 | 48 | 60 |
| Gum[7] | 0.54 | 10.6 | 40 | 8,090 | 40 | 1920 | 1280 | 113 | 35 | 6,960 | 35 | 4320 | 70 | 55 |
| Gum, cotton | 0.50 | 10.3 | 80 | 7,760 | 80 | 1580 | 1300 | 111 | 80 | 6,260 | 80 | 3760 | 160 | 60 |
| Gum, red | 0.54 | 8.7 | 182 | 9,970 | 182 | 2070 | 1590 | 120 | 182 | 7,850 | 182 | 4930 | 364 | 80 |
| Hackberry | 0.54 | 10.2 | 80 | 8,100 | 80 | 1880 | 1150 | 99 | 80 | 6,920 | 80 | 4020 | 160 | 84 |
| Hemlock, western | 0.47 | 9.7 | 119 | 9,250 | 119 | 1960 | 1580 | 112 | 119 | 6,800 | 119 | 4580 | 238 | 63 |
| Magnolia[8] | 0.58 | 8.8 | 80 | 10,830 | 80 | 2600 | 1700 | 138 | 80 | 9,220 | 80 | 5730 | 120 | 85 |
| Mahogany, African[9] | 0.52 | 12.7 | 20 | 8,070 | 20 | 2000 | 1260 | 144 | 20 | 5,370 | 20 | 3770 | ... | ... |
| Mahogany, Philippine[10] | 0.53 | 10.7 | 25 | 10,160 | 25 | 2310 | 1820 | 169 | 25 | 10,670 | 25 | 5990 | 50 | 90 |
| Mahogany, true | 0.48 | 11.4 | 35 | 8,500 | 35 | 1940 | 1250 | 117 | 35 | 6,390 | 35 | 3780 | ... | ... |
| Maple, soft[11] | 0.57 | 8.9 | 120 | 11,540 | 120 | 2420 | 1750 | 145 | 120 | 8,180 | 120 | 5380 | 240 | 106 |
| Maple, hard[12] | 0.68 | 8.0 | 202 | 15,600 | 202 | 3340 | 2110 | 189 | 192 | 10,190 | 202 | 6530 | 404 | 114 |
| Oak, commercial red | 0.59 | 9.3 | 115 | 8,500 | 115 | 2070 | 1290 | 120 | 115 | 5,480 | 115 | 3610 | 230 | 70 |
| Oak, commercial white | 0.64 | 9.5 | 195 | 10,490 | 195 | 2310 | 1340 | 118 | 195 | 6,730 | 195 | 4200 | 390 | 85 |
| Pine, sugar | 0.42 | 9.4 | 65 | 8,050 | 70 | 1670 | 1310 | 90 | 70 | 5,430 | 70 | 3690 | 140 | 47 |
| Pine, white | 0.42 | 5.4 | 40 | 10,130 | 40 | 2050 | 1570 | 111 | 40 | 5,720 | 40 | 3340 | 80 | 31 |
| Poplar, yellow | 0.50 | 9.4 | 165 | 8,860 | 165 | 1920 | 1540 | 115 | 155 | 7,390 | 165 | 4720 | 330 | 51 |
| Redwood | 0.42 | 9.7 | 105 | 8,230 | 105 | 1550 | 1180 | 108 | 105 | 4,770 | 105 | 2960 | 210 | 48 |
| Spruce, Sitka | 0.42 | 8.3 | 121 | 7,710 | 121 | 1690 | 1370 | 105 | 121 | 5,650 | 121 | 3410 | 224 | 78 |
| Sycamore | 0.56 | 9.2 | 163 | 11,040 | 163 | 2340 | 1630 | 130 | 163 | 8,030 | 163 | 5220 | 326 | 77 |
| Walnut, black | 0.59 | 9.1 | 110 | 12,660 | 110 | 2770 | 1740 | 141 | 110 | 8,250 | 110 | 5260 | 220 | 77 |
| Yucca species | 0.49 | 7.3 | 33 | 2,960 | 33 | 900 | 560 | 44 | 33 | 2,210 | 33 | 1700 | 66 | 14 |

[1] Parallel and perpendicular refer to the direction of the grain of the faces relative to the direction of the application of the force.
[2] The relative splitting resistance of the various panels tested depends largely on the holding strength of glue.
[3] Probably black cherry.
[4] Probably (common) cottonwood.
[5] Coast type.
[6] Probably white fir.
[7] Probably black gum.
[8] Probably (evergreen) magnolia.
[9] Probably Khaya sp.
[10] Probably tanguile.
[11] Probably silver maple.
[12] Sugar or black maple.

NOTE.—In some of the species listed above the tests are rather limited in number. Since there is considerable variation in the strength of wood, further tests on additional material would be expected to modify the values appreciably in some cases.

### Explanation of Table 2

The data of Table 2 may be used to compute the thickness of three-ply wood members of various species when the forces acting on these members are known. The strength in bending is given by the column-bending modulus, which may be used in computations in a capacity similar to the modulus of rupture of ordinary wood. The direction in which the external forces act on the member relative to the direction of the face grain of the plywood must be taken into consideration in using the data. The strength values correspond to the moisture contents listed.

### Types of Plywood Construction

Several of the more commonly used types of plywood construction are shown in Fig. 7, and a still wider range can be secured by combining veneer and lumber. Many other variations and combinations can be made in plywood construction, with more plies, or even number of plies, or angular and radial grain arrangements, each having its particular use and purpose.

*Plywood With Equal Thickness of Each Ply.* Plywood made with plies of equal thickness had a purely utilitarian origin, i.e., to use the best veneers for the faces, the next for the back, and the poorest for the inside layers, thus working up the entire product of the log. Door panels are customarily made of three thicknesses $^1/_7$ in. thick sanded down so as to fit into a $^3/_8$-in. groove, or five thicknesses $^1/_9$ in. thick fitted to a $^5/_8$-in. groove, depending on the size of the panel.

Some stock panels are made in this way, but $^1/_4$-in. stock panels are more often made with a $^3/_{16}$-in. veneer core and $^1/_{20}$-in. face and back.

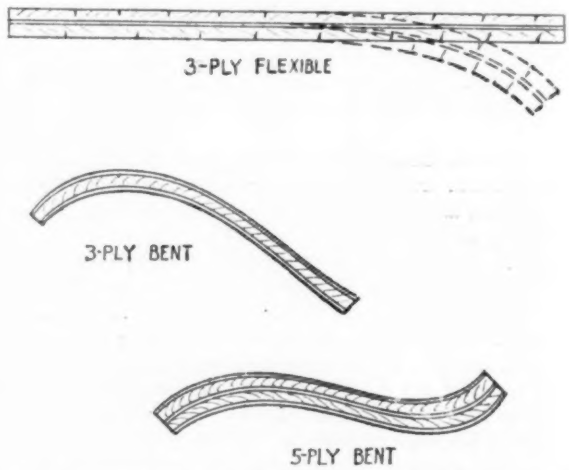



FIG. 8 FLEXIBLE AND CURVED PLYWOOD SHOWING RELATION OF THICKNESSES AND BENDING. BENDING WITH THE GRAIN IS EASY AND POSSIBLE ON THICK VENEER. BENDING AGAINST THE GRAIN SHOULD BE ONLY ON THIN VENEER

This same style of construction with plies of equal thickness is used for player-piano bellows stock and automobile instrument boards, dashboards, floor boards, and the like, although

TABLE 3 THICKNESS FACTORS FOR VENEER

[Giving: (1) Veneer thickness for the same total bending strength as birch ($K_s$); (2) veneer thickness for the same weight as birch ($K_w$).]

| Species | $D$ Average specific gravity of species[11] based on oven-dry weight and air-dry volume | Specific gravity of glued plywood as tested, based on oven-dry weight and volume at test | Moisture content of plywood as tested, per cent | $S$ Unit bending strength compared with birch,[1] per cent | $K_s$ Thickness factor for the same total bending strength as birch, $\sqrt{\frac{100}{S}}$ | $K_w$ Thickness factor for the same weight as birch, $\frac{0.63}{D}$ |
|---|---|---|---|---|---|---|
| Ash, black | 0.50 | 0.49 | 9.1 | 52 | 1.39 | 1.26 |
| Ash, commercial white | 0.58 | 0.60 | 10.2 | 72 | 1.18 | 1.09 |
| Basswood | 0.38 | 0.42 | 9.2 | 48 | 1.44 | 1.66 |
| Beech | 0.63 | 0.67 | 8.6 | 94 | 1.03 | 1.00 |
| Birch, yellow | 0.63 | 0.67 | 8.5 | 100 | 1.00 | 1.00 |
| Cedar, Spanish | 0.34 | 0.41 | 13.3 | 43 | 1.52 | 1.85 |
| Cherry[2] | 0.51 | 0.56 | 9.1 | 80 | 1.12 | 1.24 |
| Chestnut | 0.44 | 0.43 | 11.7 | 34 | 1.72 | 1.43 |
| Cottonwood | 0.43 | 0.46 | 8.8 | 56 | 1.34 | 1.47 |
| Cypress, bald | 0.44 | 0.45 | 8.0 | 57 | 1.32 | 1.43 |
| Douglas fir[3] | 0.51 | 0.48 | 8.6 | 60 | 1.29 | 1.24 |
| Elm, cork | 0.66 | 0.62 | 9.4 | 78 | 1.13 | 0.95 |
| Elm, white | 0.51 | 0.52 | 8.9 | 58 | 1.13 | 1.24 |
| Fir, true[4] | 0.38 | 0.40 | 8.5 | 57 | 1.32 | 1.66 |
| Gum[5] | 0.52 | 0.54 | 10.6 | 55 | 1.35 | 1.21 |
| Gum, cotton | 0.52 | 0.50 | 10.3 | 49 | 1.43 | 1.21 |
| Gum, red | 0.49 | 0.54 | 8.7 | 64 | 1.25 | 1.29 |
| Hackberry | 0.54 | 0.54 | 10.2 | 55 | 1.35 | 1.17 |
| Hemlock, western | 0.42 | 0.47 | 9.7 | 60 | 1.29 | 1.50 |
| Magnolia[6] | 0.51 | 0.58 | 8.8 | 74 | 1.16 | 1.24 |
| Mahogany, African[7] | 0.46 | 0.52 | 12.7 | 56 | 1.34 | 1.37 |
| Mahogany, Philippine[8] | 0.57 | 0.53 | 10.7 | 68 | 1.21 | 1.10 |
| Mahogany, true | 0.49 | 0.48 | 11.4 | 57 | 1.32 | 1.29 |
| Maple, soft[9] | 0.48 | 0.57 | 8.9 | 74 | 1.16 | 1.31 |
| Maple, hard[10] | 0.62 | 0.68 | 8.0 | 100 | 1.00 | 1.02 |
| Oak, commercial red | 0.63 | 0.59 | 9.3 | 59 | 1.30 | 1.00 |
| Oak, commercial white | 0.69 | 0.64 | 9.5 | 69 | 1.20 | 0.91 |
| Pine, sugar | 0.37 | 0.42 | 9.4 | 51 | 1.40 | 1.70 |
| Pine, white | 0.39 | 0.42 | 5.4 | 64 | 1.25 | 1.61 |
| Poplar, yellow | 0.41 | 0.50 | 9.4 | 58 | 1.31 | 1.54 |
| Redwood | 0.36[12] | 0.42 | 9.7 | 50 | 1.41 | 1.75 |
| Sycamore | 0.50 | 0.56 | 9.2 | 71 | 1.19 | 1.26 |
| Spruce, Sitka | 0.38 | 0.42 | 8.3 | 50 | 1.41 | 1.66 |
| Walnut, black | 0.57 | 0.59 | 9.1 | 83 | 1.10 | 1.10 |
| Yucca species | .. | 0.49 | 7.3 | 23 | 2.09 | .. |

[1] Average of the column bending moduli parallel and perpendicular to grain compared to birch, based on tests of 3-ply wood, each ply one-third of the total panel thickness.
[2] Probably black cherry.
[3] Coast type.
[4] Probably white fir.
[5] Probably black gum.
[6] Probably (evergreen) magnolia.
[7] Probably Khaya species.
[8] Probably tanguile.
[9] Probably silver maple.
[10] Probably sugar or black maple.
[11] Values of domestic species taken from U. S. Department of Agriculture Bulletin 556, Mechanical Properties of Woods Grown in the United States.
[12] Based on tests not included in Bulletin 556.

the core wood often is of a different species and sometimes of a different thickness from face and back, thereby departing from the original utilitarian urge.

*Flexible and Bent Plywood.* Veneers do not bend easily against the grain, hence a flexible panel may be made with a very thin core of veneer and thick faces of loose-cut veneer. (See Fig. 8.) The old-fashioned sleigh was made using this class of plywood. The combined flexibility and stiffness of such plywood is surprising.

Bent plywood carries this flexible plywood idea one stage further. The reverse-curve opera seat should be bent rigid, not flexible, hence if a face and back of thin veneer are glued on to the above 3-ply flexible panel, it will result in a rigid bent 5-ply panel. It is, of course, made in one gluing operation and pressed and dried in nested cauls or dies.

This rigid bent plywood can also be made in 3-ply, using a thin face and back, and a thick, loosely cut core, bending the core with the grain. This is cheaper and not equal to the 5-ply seat.

*Plymetal.* Not only is it possible to produce combinations of different woods through a series of thicknesses and through various methods of assembling of wood veneers, but a new field appears in which wood-fiber board and metal may be "plied" together in various combinations. This will require a careful study of suitable glues and adhesives, but the opportunity is most promising.

### Explanation of Table 3

When substituting one species for another in airplane plywood it is desirable to know the thickness of veneer which will give either the same bending strength or the same weight as the original material. The thickness factors $K_s$ and $K_w$ given in Table 3 will be found useful for this purpose. For instance, the thickness of basswood veneer required to afford approximately the same bending strength as one-tenth inch yellow poplar, may be obtained by multiplying the thickness of the yellow poplar by the ratio of the thickness factor ($K_s$) of basswood to that of yellow poplar. The factor $K_w$ may be used in a similar computation to obtain the thickness of one species required to equal the weight of another.

### The Testing of Plywood

The possibility of using plywood in the manufacture of airplanes, fuselages, and wing-beam covers and for many purposes where heavy silk and other fabrics were previously used was a war development, and Government departments were immediately put to work investigating the subject. Starting with the proved fact that laminated wood or plywood may be stronger than steel, weight for weight, of what practical use could this have been in winning the war?

Considerable literature was developed by the Forest Products Laboratory at Madison, Wis., but the results are too new, the scope of the investigations too limited, and our perspective is too short to do full justice to the subject.

The testing of veneer was chiefly as a component part of plywood to determine what any single ply might do under various conditions. The weights of commercial species of veneer (Table 1)[3] were determined, but it was found that different trees of a single species yielded veneer of somewhat varying weights—heart wood was heavier than sap, highland and lowland growths had different textures, and so on.

Table 1 should be used in determining the approximate weights per square foot of oven-dry veneer. Utilizing the glue weight given, it is possible to compute the weight of plywood and reduce it to pounds per square foot. Table 2 is developed for the purpose of computing the approximate tensile strength of plywood per square inch. Table 3 gives thickness factors for determining the thickness required in basswood or ash to be equivalent to yellow birch.

In addition to the tables on veneer tests just described, another

[3] "Data on the Design of Plywood for Aircraft," National Advisory Committee for Aeronautics, Report No. 84, 1920.

Table 4 (from Report No. 84) is given, showing the strength of the various species of wood when made into 3-ply.

Both of these series of tests, however, relate to the development of ultimate strength in plywood and apply to airplane design rather than to other industries where abundant strength can be obtained by sufficient size and weight.

Tests of commercial glues have a much wider application than the veneer and plywood tests outlined above. The glue tests fall into two general forms, one for the constituents and qualities of the glue in powder and fluid form,[4] and the other for the strength of joints made in various ways with different glues.

The British and the United States Governments have adopted similar methods for testing the strength of a plywood glued joint. Pieces of veneer are glued up into plywood, of the size and arrangement shown in Fig. 9. The arrangements of transverse grooves is such that when the samples are pulled apart in a tensile testing machine the separation must come on either one or both of the glue lines, or in the short center piece of veneer core.

The difficulty with this test is the lack of uniformity in mixing and applying glues to different woods under varying pressures. There are too many variable elements to isolate clearly the one of glue-joint strength. This method, however, gives satisfactory comparative tests where an unknown glue is tested under

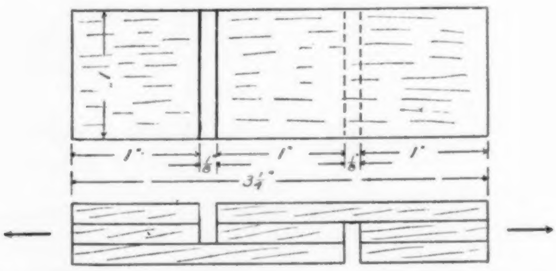



Fig. 9 Glue Test Specimen as Made for the Manufacture of Plywood, Adopted by the American and British Governments During the Recent War

similar conditions with one whose qualities are known to be satisfactory.

Another similar shear test but under compression rather than tension is usually made by gluing blocks of hard maple together and pushing rather than pulling apart.

### Explanation of Table 4

Table 4 lists the tensile strength of 3-ply wood of various common veneer species and the approximate strength of single-ply wood. The strength figures, given in pounds per square inch, correspond to the moisture contents listed.

*Sample Computation:* To obtain the tensile strength of 3-ply wood consisting of two $^1/_{20}$-in. birch faces and a $^1/_{16}$-in. basswood core:

Tensile strength parallel to face grain $= 2 \times {}^1/_{20} \times 19{,}820 = 1982$ lb. per in. of width.

Tensile strength perpendicular to face grain $= 1 \times {}^1/_{16} \times 10{,}320 = 645$ lb. per in. of width.

This computation neglects the tensile strength of the ply or plies perpendicular to the grain, which is comparatively small, and the results are therefore slightly in error.

The mechanical properties of wood are quite variable, and the strength of individual pieces may be expected to differ considerably from the average values given.

TABLE 4 TENSILE STRENGTH OF PLYWOOD AND VENEER

| Species | Number of tests | Moisture content at test, per cent | Specific gravity[1] of plywood | Tensile strength[2] of 3-ply wood parallel to grain of faces, lb. per sq. in. | Tensile strength[3] of single-ply veneer 1/2 (d), lb. per sq. in. |
|---|---|---|---|---|---|
| | (a) | (b) | (c) | (d) | (e) |
| Ash, black | 120 | 9.1 | 0.49 | 6,180 | 9,270 |
| Ash, commercial white | 200 | 10.2 | 0.60 | 6,510 | 9,760 |
| Basswood | 200 | 9.2 | 0.42 | 6,880 | 10,320 |
| Beech | 120 | 8.6 | 0.67 | 13,000 | 19,500 |
| Birch, yellow | 200 | 8.5 | 0.67 | 13,210 | 19,820 |
| Cedar, Spanish | 115 | 13.3 | 0.41 | 5,200 | 7,800 |
| Cherry[4] | 115 | 9.1 | 0.56 | 8,460 | 12,690 |
| Chestnut | 40 | 11.7 | 0.43 | 4,430 | 6,640 |
| Cottonwood[5] | 120 | 8.8 | 0.46 | 7,280 | 10,920 |
| Cypress, bald | 113 | 8.0 | 0.45 | 6,160 | 9,240 |
| Douglas fir[6] | 200 | 8.6 | 0.48 | 6,180 | 9,270 |
| Elm, cork | 65 | 9.4 | 0.62 | 8,440 | 12,660 |
| Elm, white | 160 | 8.9 | 0.52 | 5,860 | 8,790 |
| Fir, true[7] | 24 | 8.5 | 0.40 | 5,670 | 8,510 |
| Gum[8] | 35 | 10.6 | 0.54 | 6,960 | 10,440 |
| Gum, cotton | 80 | 10.3 | 0.50 | 6,260 | 9,390 |
| Gum, red | 182 | 8.7 | 0.54 | 7,850 | 11,780 |
| Hackberry | 80 | 10.2 | 0.54 | 6,920 | 10,380 |
| Hemlock, western | 119 | 9.7 | 0.47 | 6,800 | 10,200 |
| Magnolia[9] | 80 | 8.8 | 0.58 | 9,220 | 13,830 |
| Mahogany, African[10] | 20 | 12.7 | 0.52 | 5,370 | 8,060 |
| Mahogany, Philippine[11] | 25 | 10.7 | 0.53 | 10,670 | 16,000 |
| Mahogany, true | 35 | 11.4 | 0.48 | 6,390 | 9,580 |
| Maple, soft[12] | 120 | 8.9 | 0.57 | 8,180 | 12,270 |
| Maple, hard[13] | 192 | 8.0 | 0.68 | 10,190 | 15,290 |
| Oak, commercial red | 115 | 9.3 | 0.59 | 5,480 | 8,220 |
| Oak, commercial white | 195 | 9.5 | 0.64 | 6,730 | 10,100 |
| Pine, sugar | 110 | 8.0 | 0.42 | 5,530 | 8,300 |
| Pine, white | 40 | 5.4 | 0.42 | 5,720 | 8,580 |
| Poplar, yellow | 155 | 9.4 | 0.50 | 7,390 | 11,080 |
| Redwood | 105 | 9.7 | 0.42 | 4,770 | 7,160 |
| Spruce, Sitka | 121 | 8.3 | 0.42 | 5,650 | 8,480 |
| Sycamore | 163 | 9.2 | 0.56 | 8,030 | 12,040 |
| Walnut, black | 110 | 9.1 | 0.59 | 8,250 | 12,380 |
| Yucca species | 33 | 7.3 | 0.49 | 2,210 | 3,320 |

[1] Specific gravity based on oven-dry weight and volume at test.
[2] Based on total cross-sectional area.
[3] Based on assumption that center ply carries no load.
[4] Probably black cherry.
[5] Probably (common) cottonwood.
[6] Coast type.
[7] Probably white fir.
[8] Probably black gum.
[9] Probably (evergreen) magnolia.
[10] Probably Khaya species.
[11] Probably tanguile.
[12] Probably silver maple.
[13] Sugar or black.
Data based on tests of 3-ply panels with all plies in any one panel same thickness and species.

### Conclusion

The engineering field offers many other openings for the economic and effective use of a plywood that is strong for its weight as well as thoroughly waterproof.

The maker and the user of plywood may well join forces in striving to bring about a better understanding of plywood in its many aspects, in an intensive development of the processes of making plywood, and a broader utilization for both economic and utilitarian purposes.

## Discussion

Charles B. Norris.[5] I would like to make a few additions to the paper, in parts that might possibly be a little misleading. The author says, "Cross-veneering or cross-layers in plywood also have a tendency to counterbalance stresses and uneven shrinkage in the wood, and thereby prevent the manifestation

[4] A bulletin describing "Standard Methods for Determining Viscosity and Jelly Strength," adopted by the National Association of Glue Manufacturers at Atlantic City, Oct. 10, 1923, may be obtained from the National Association of Glue Manufacturers, 1355 West 31st Street, Chicago, Ill.

See also "Recent Advances in Methods of Glue Evaluation," by Wilbur L. Jones, Mechanical Engineering, vol. 47, no. 11a, Mid-November, 1925, p. 1072.

[5] Mechanical Engineer, Haskelite Mfg. Corp., Grand Rapids, Mich. Mem. A.S.M.E.

of the internal stresses that are an element of weakness in solid wood." The word "manifestation" is well chosen, because the stresses are there. In fact, the internal stresses of plywood are likely to be greatly in excess of those found in ordinary wood. In some cases, where the panel is rather thick and the core is also thick with respect to the thickness of the panel, plywood panels have large longitudinal shear stresses due to the internal forces built up. But these stresses in plywood are balanced so that they do not tend to warp the plywood. They are balanced in the degree that when the panels fail in longitudinal shear, they show no signs of warping until the failures have actually occurred. Then, of course, there are some signs of warping.

The author also says, "Since wood, as stated before, has a greater resistance to shear sidewise than along the grain, and because this shear in bending acts in the direction of the span parallel with the top and bottom fibers, it is perfectly apparent that layers of veneer placed crosswise in plywood increase this resistance to this longitudinal shear." The meaning of that paragraph evidently is that the likelihood of failure in longitudinal shear is decreased. It is; but another factor is involved—the rigidity of wood is much less across the grain than with the grain. Therefore in a piece of plywood there is a much greater tendency for the layers to slip over each other than would be the case if the layers were glued with the grain of all layers lying in the same direction. This means that the wood, under certain conditions, could be bent without inordinately increasing the compression strains that would naturally result from such bending.

In another place the author says, "When such a laminated board is made with similar cross-layers directly under these outer layers, the board will have a similar resistance to bending in the opposite direction, but not so great because the layers are nearer together and have the effect of a board of so much less thickness." This is approximately true in the average case of plywood panels, say three-ply panels, where the faces have about the same longitudinal thickness as the core. There are some special cases, however, which are important enough to be considered. For instance, it is evident that a piece of three-ply plywood, having a core which is thick compared to the thickness of the total piece of plywood and having very thin faces, will act like a board whose grain is in the direction of the core. On the other hand, a piece of three-ply plywood with an exceedingly thin core and thick faces will act like a board whose grain runs in the direction of the faces. Undoubtedly somewhere between those two limits there will be a construction of three-ply plywood which will have exactly the same strength in both directions. In fact, such a construction can be rather readily determined mathematically. Also, between these two extreme constructions, there is a construction of plywood that has the same stiffness in both directions.

It is interesting to note that if the problem is analyzed mathematically the construction for equal stiffness in both directions is found not to be the same as that for equal strength in both directions. It is important to call attention to this fact because the real advantage in plywood is that the construction can be designed to suit the particular purpose the designer has in mind.

In discussing albumin glue, the author says, "This coagulation takes place from 175 to 200 deg. fahr., and veneer thicker than $^1/_{16}$ in. is likely to discolor from heat during coagulation." We have found that discoloration can be controlled by controlling the temperature. In fact, faces of plywood as thick as $^1/_4$ in. can be glued without any discoloration.

The author adds, "Each layer of veneer applied requires separate coagulation." That limitation also has been overcome. We often glue up seven- and five-ply panels in a single operation.

C. W. Coye.[6] It would be unseemly for a non-technical representative of a comparatively non-engineered industry to discuss in technical detail the paper just presented. The author has touched on a few of the many factors involved in the production of plywood, indicating that his profession has a thorough understanding of them and the need for further study of plywood production and use, control of production factors, further development of comparative tests, and research of partially developed and potential markets.

Every new or partially developed use for any product must go through an experimental stage with the cooperation of both the consuming and producing branches. It is during the development or experimental stage that both factors need the kindly guidance of the engineering profession.

It is perhaps safe to say that only recently has the woodworking industry in its several branches been discovered as a fertile field by the strictly technical profession. As yet a great many, perhaps the majority, of the large commercial units in the woodworking industry are without the benefit of technical advice from within their own personnel. While many manufacturers of the thousands comprising the woodworking industry have at least one technical man on their staff, the bulk of them are dependent upon outside advices or, as is done largely, accept what is brought to them without studying any of the technical phases of the material. Some of these technically uneducated commercial units comprise a very large market for plywoods of various sorts, but because of the lack of any definite basis to purchase on and because of insufficient study of their plywood requirements they have selected materials with which they have had unfortunate experiences. Such experiences have weakened their faith, and even though its superior appearance value stimulates trade, the manufacturer of the product finds the replacement of plywood parts so heavy that he hesitates to use it in his goods.

It is not unreasonable to expect that eventually research and dissemination of the results will progress to the point where the large markets, both in the engineering and the commercial fields, can purchase on a detailed specification basis with a consideration of all factors of production and use involved. Already there are standards for the production of plywoods for the aircraft industry, and it is bought largely on a specification basis. It is true that the standards have been fostered by the Government, but most of the users of aircraft plywoods use the same standards.

The engineering profession has indicated the possibilities of study in the plywood-producing industry and has made great strides in analyzing the engineering characteristics and possibilities of the material. The next step must be one of further study and a translation of the results into standards for both the technical and non-technical user.

Many companies are forced to accept material brought to them without technical research and advice and without a thorough knowledge of whether that material is particularly suited to their uses. There are many instances where certain branches of the woodworking industry have selected plywoods because of their appearance value and because their trade demands the appearance value a plywood assures, and have had very unfortunate experiences with it and have been forced to use less of it or to cease using it entirely, even in the face of a large demand for that particular product.

Plywood is being purchased for specific purposes and from, I might say, specific units in the plywood-producing industries on a specification basis. It is not unreasonable to asume that, later, plywood can be engineered or that standards can be set up so that any industry can buy the plywood for a particular purpose on the specification basis. This to me is the outstanding feature of the paper. An engineering knowledge of plywoods has

[6] Alaska Refrigerator Co., Muskegon, Mich.

been established and that it should be further developed is necessary so that it will be possible to buy on the specification basis.

In the refrigerator industry there has been a large call for plywood doors because of the smooth appearance that it gives to the refrigerator. One factory used perhaps two cars of plywood last year, and the replacement was about 10 per cent. This is not an unsolvable problem, but the company has been forced to discontinue the use of plywood entirely because the plywood they had been using had not been properly specified, because they were without technical advice in their own industry, and because the plywood producers were unable to give them that technical advice.

C. S. Welch.[7] A discussion of plywood which would be impervious to atmospheric changes, possibly through impregnation, would be of very great interest, and I am of the belief that very little has been done along this line in the manufacture of plywood.

The author stresses the point that very little has been done in substituting plywood for solid wood in most of our manufacturing for engineering purposes. This is entirely true, and the next few years will bring forth uses of plywood in cases where now no thought has been given to this possibility.

Ralph K. Merrill.[8] In his description of the uses of plywood, the author gives a number of the properties of plywood when used in building stateroom partitions on board ship. He makes the statement that the resistance to the transmission of sound is greater than solid wood or metal. Are we to take that as meaning that it is less likely to absorb sound or to reverberate, i.e., to reflect sound?

Furthermore, some definition of the terms "plywood" and "veneered" panels should come out of this meeting. It should be clearly stated where one leaves off and the other begins, if it does begin at all; whether we are to consider that the panel made up of a very thick core, such as Mr. Norris has referred to, and covered with a thin sheet of wood, is to be known as a veneered panel or a plywood panel and whether such panels are now good practice in the furniture trade or any other.

Undoubtedly, the three-ply with a very thick core makes a panel which is in itself very superior to solid wood, regardless of what the wood may be, in its resistance to warping, checking, swelling, and so on.

I have noticed that on the edge of a piece of seven-ply plywood, say $^{13}/_{16}$ in. thick, the plies are quite visible, and the wider the panel, the more visible they become. Is this a characteristic of plywood or is it due to extreme haste in manufacture, indicating the lack of drying the center plies in the present type of plate dryer, or is it because it was sanded and finished too soon after it was glued?

D. J. McLaughlin.[9] I was a little disappointed that the author had nothing to say about the preparation of cross-banding and veneer for laying and the redrying of the cores before laying finished veneer. Mr. Norris has said that the five-ply and seven-ply are sometimes built up in one operation. On the other hand, on a large table-top construction, it has been our practice to build the plies separately, redrying after each gluing operation, to guarantee a minimum of shrinkage in the finished work. My suggestion would be that at some future date we have a paper on drying and redrying which is so important a part of properly building plywood.

[7] The Brunswick-Balke-Collender Co., Muskegon, Mich.

[8] Industrial Mechanical Engineer, American Seating Co., Grand Rapids, Mich. Mem. A.S.M.E.

[9] Superintendent Wood Division, Yawman-Erbe Mfg. Co. Assoc-Mem. A.S.M.E.

Mr. Norris. In speaking about gluing five- and seven-ply panels in one operation, I should explain that the panels were intended for structural purposes and not for furniture. It was not necessary that they be good looking. In regard to the terms "plywood" and "veneer," during the war or shortly afterward the Forest Products Laboratory, which is a Federal Government institution, decided to call all panels built up of veneer "plywood" and to call the different layers themselves "veneer."

D. Olander.[10] In regard to moisture-proofing wood we have tried out a process, and in the case of one species of wood it was apparently possible to reduce swelling practically completely. In general the reduction amounted to 50 per cent or more.

I believe the possibilities are very good, providing sapwood is used and also with the heartwood of certain species. It is a preservative process and seems largely a question of getting enough of the preservative into the wood. We tried some Sitka spruce which had been treated and found that at a relative humidity of 88 per cent which was maintained for several weeks there was no indication of swelling so far as we could measure.

O. M. Dunton.[11] In line with Mr. Merrill's remarks as to the expansion of plywood due to the internal stresses, and also in line with Mr. Welch's first paragraph, I recall an article on plywood which told of a study which was being made on closing the pores and making it impervious to moisture. This process is the impregnation of plywood with chemicals which will make it impervious to moisture. I am wondering what success has been made along that line, if any.

William Braid White.[12] A word was said about sound transmission through solid woods as compared with the same process through plywoods, and again with reference to the general question of reflection or absorption. In the first place, very little work has been done on the subject.

Secondly, if transmission through a piece of wood is meant, then it follows that the more the plywood is built up or the more plies there are in the plywood, the less transmission there will be through them, so that transmission in the case of plywood would be very small indeed, probably negligible as compared with metal.

Thirdly, reflection of sound, other things being equal, becomes solely a question of the surface hardness. If, therefore, the outer ply of a piece of plywood is of the same species as the solid wood, other things being equal, their reflective qualities will be the same. The height of the index will depend entirely upon the surface hardness. That also will apply to metal. Other things being equal, a sheet of steel, for instance, will have a higher reflective index.

On the other hand, reversing the effects, a parallel result will be found with regard to absorption. If it is desired to absorb sound, other things being equal, more will be absorbed from any known wood, except possibly one or two of the extremely hard woods, than from steel.

### Author's Closure

Mr. Merrill raises the question of the sound-resistant qualities of plywood compared with metal or other wood. I think, compared with metal, plywood will not transmit sound as will metal. Neither will plywood transmit sound as well as solid wood. Mr. White has covered this in his discussion.

On the question of the proper use of the terms "veneer" and "plywood," I believe the term "veneer" should be applied to thin

[10] Baldwin Company, Cincinnati, Ohio.

[11] American Seating Company, Grand Rapids, Mich.

[12] Consulting Acoustic Engineer, American Steel & Wire Co., Chicago, Ill. Mem. A.S.M.E.

single sheets and that as an adjective the word "veneered" is misleading. Plywood is made up of sheets of veneer. If this phraseology is used, much confusion will be avoided.

With regard to the value of three- or five-ply plywood, there is no question that five-ply is better than three-ply, but it is also more expensive. I think that the value of three- or four-ply in certain products rests largely on an economic base.

Many attempts at impregnation of plywood have been made, but in every instance that I know of impregnation has added so much weight that it has largely eliminated the strength-for-weight advantage. That is, anything that fills the pores of the wood and renders it impervious to moisture adds so greatly to the weight as to throw plywood out of its particular function. There are quite a number of such processes.

There are some other developments in certain research channels looking toward gaseous impregnation of woods, with a later liquefaction or solidification of those gases in the pores of the wood by another gas, a much lighter impregnation than is possible by the liquid processes. The process is in the laboratory stage now, and no one can predict what will come of it.

# Efficiency Methods and Standards in German Woodworking Industries

## A Brief Description of Work Being Carried on in Germany for the Purpose of Attaining Higher Efficiency in Woodworking

By ROBERT SCHLUETER,[1] GERMANY

IN ADDRESSING mechanical engineers there is no need to explain the necessity of obtaining greater engineering efficiency in industries, no matter where located, in the United States, in Germany, or elsewhere. It has been the engineer who has originated research and technical supervision in the industrial field, with the aim of obtaining better quality, lower costs, and greater safety.

In 1921 the Verband Technisch-wissenschaftlicher Vereine (The Association of Technical and Scientific Societies) in coöperation with the German Government's Department of Economics, started the Reichskuratorium für Wirtschaftlichkeit (German National Committee for Promoting Industrial, Commercial and Agricultural Efficiency), generally called the "RKW." This association works under the auspices of the German Government, but is entirely controlled and managed by the industries themselves through committees made up of experts in the various above-mentioned industries. The government provides the expenses of management. The cost of research is usually contributed by the industry concerned, either in cash or by sending engineers and other experts to the different meetings and conventions of the RKW.

The RKW works through its *Ausschüsse* (committees) which operate in direct connection with the different groups in industries, commerce, and agriculture.

Fig. 1 gives an idea of the organization of the RKW. But it must be understood that this sketch shows a very small part of the committee's activities, just enough to illustrate its relation to the woodworking field.

It goes without saying that none of these sub-committees works for itself, but all interchange their results among themselves and with the committees representing other lines, as, e.g., the committees on technical teaching, organization, textiles, forging, welding, etc.

| | | |
|---|---|---|
| *Reichskuratorium für Wirtschaftlichkeit* (German National Committee for Promoting Industrial, Commercial and Agricultural Efficiency) | → *Normenausschuss* (Committee on Standards) | → *Unterausschuss für Normung in der Holzindustrie* (Sub-Committee on Standards in the Wood Industries) |
| | → *Ausschuss für wirtschaftliche Fertigung* (Committee on Economical Manufacturing) | → *Unterausschuss für wirtschaftliche Fertigung in der Holzindustrie* (Sub-Committee on Economical Manufacturing in the Wood Industries) |
| | → *Ausschuss für Lieferungsbedingungen* (Committee on Specifications) | → *Unterausschuss für Lieferungsbedingungen in der Holzindustrie* (Sub-Committee on Specifications in the Wood Industries) |
| | → *Ausschuss für Arbeitszeitermittlung* (Committee on Time Studies) | → *Unterausschuss für Arbeitszeitermittlung in der Holzindustrie* (Sub-Committee on Time Studies in the Wood Industries) |
| | → *Ausschuss für Förderwesen* (Committee on Handling Materials) | → *Unterausschuss für Förderwesen in der Holzindustrie* (Sub-Committee on Handling Materials in the Wood Industries) |

FIG. 1 ORGANIZATION OF THE RKW (GERMAN NATIONAL COMMITTEE FOR PROMOTING INDUSTRIAL, COMMERCIAL, AND AGRICULTURAL EFFICIENCY)

The best way to explain the work done by the sub-committees will be by means of some examples.

The Unterausschuss für Normung in der Holzindustrie (Sub-Committee on Standards in Wood Industries), together with the Verband deutscher Holzbearbeitungsmaschinen-Fabriken (Association of the Manufacturers of Woodworking Machinery), works on standards for interchangeable parts of woodworking machinery, having first revised all the published standards for machinery in the other industries with respect to their application to the woodworking field.

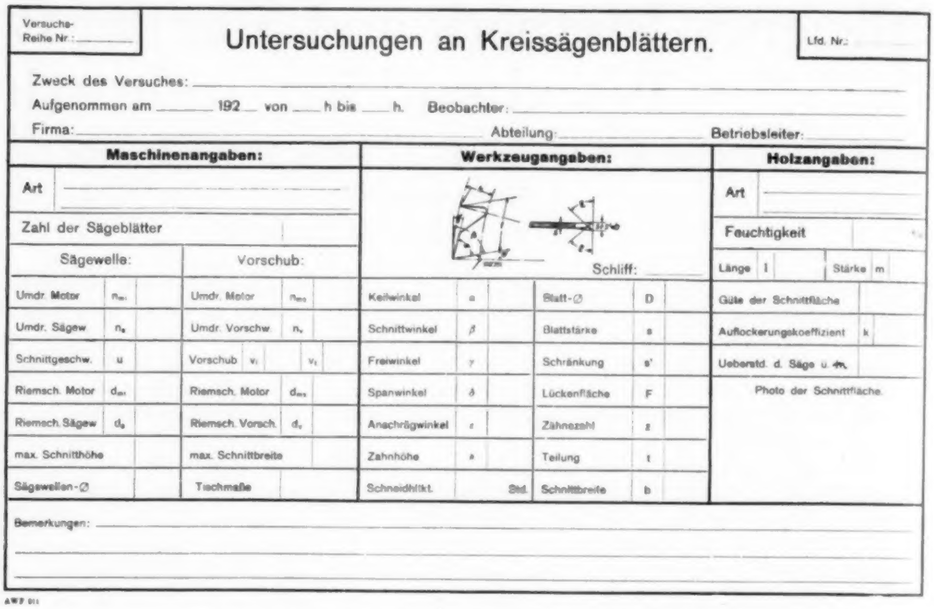
Fig. 2 shows the adopted standard for cap nuts for the spindles of shapers. No matter what kind of shaper one buys, these cap nuts will always be the same and interchangeable. The engineer, the man out in the field, will understand what a big advantage

[1] Diplom-Ingenieur, Member of the German Committee on Economical Manufacturing in the Wood Industries.

Presented at the Third National Meeting of the A.S.M.E. Wood Industries Division, Grand Rapids, Mich., November 26 and 27, 1928.

this is. The figure shows just one out of numerous standardized parts of shapers. These standards are published and copyrighted by the Deutscher Normenausschuss (German Committee on Standards), and printed by the Beuth-Verlag, G.m.b.H., Berlin S 14.

The Unterausschuss für wirtschaftliche Fertigung in der Holzindustrie (Sub-Committee on Economical Manufacturing in the Wood Industries), besides its work on manufacturing methods and on machinery (the right machine in the right place), carries on research work on saws and knives. Fig. 3 is a reproduction of specifications for research on circular saws, showing plainly how many different factors have to be considered to get real practical results. The necessary



Versuchs-Reihe Nr.:

Untersuchungen an Kreissägenblättern.

Lfd. Nr.:

Zweck des Versuches:

Aufgenommen am ____ 192__ von __ h bis __ h. Beobachter:

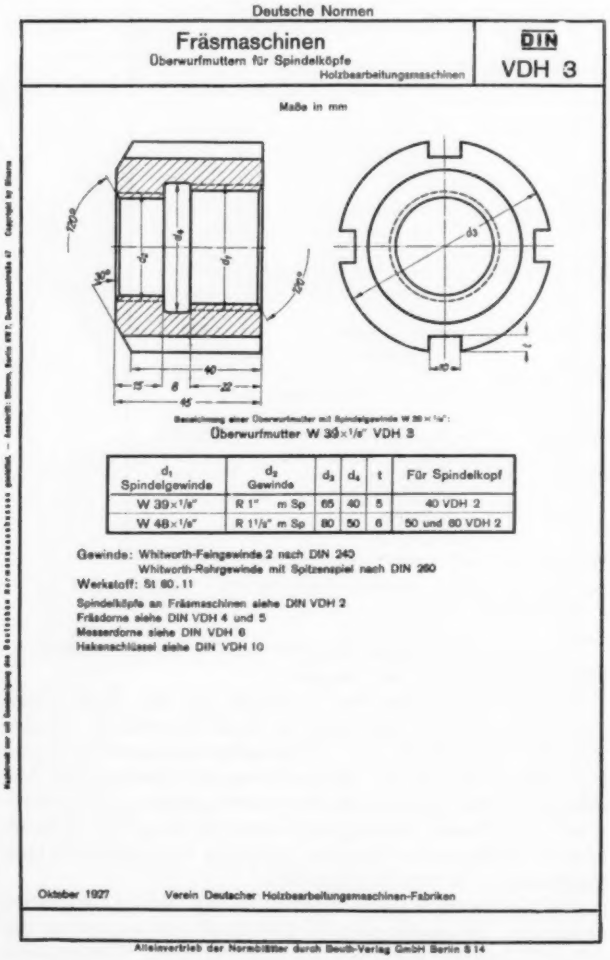
Firma: Abteilung: Betriebsleiter:

| Maschinenangaben: | | | | Werkzeugangaben: | | | | Holzangaben: | |
|---|---|---|---|---|---|---|---|---|---|
| Art | | | | | | | | Art | |
| Zahl der Sägeblätter | | | | | | | | Feuchtigkeit | |
| Sägewelle: | | Vorschub: | | | | Schliff: | | Länge l | Stärke m |
| Umdr. Motor | $n_{m1}$ | Umdr. Motor | $n_{m2}$ | Keilwinkel | $\alpha$ | Blatt-Ø | D | Güte der Schnittfläche | |
| Umdr. Sägew. | $n_s$ | Umdr. Vorschw. | $n_v$ | Schnittwinkel | $\beta$ | Blattstärke | s | Auflockerungskoeffizient | k |
| Schnittgeschw. | u | Vorschub | $v_1$ $v_2$ | Freiwinkel | $\gamma$ | Schränkung | s' | Ueberstd. d. Säge ü. Holz | |
| Riemsch. Motor | $d_{m1}$ | Riemsch. Motor | $d_{m2}$ | Spanwinkel | $\delta$ | Lückenfläche | F | Photo der Schnittfläche. | |
| Riemsch. Sägew. | $d_s$ | Riemsch. Vorsch. | $d_v$ | Anschrägwinkel | $\varepsilon$ | Zähnezahl | z | | |
| max. Schnitthöhe | | max. Schnittbreite | | Zahnhöhe | h | Teilung | t | | |
| Sägewellen-Ø | | Tischmaße | | Schneidhltkt. | Std. | Schnittbreite | b | | |

Bemerkungen:

AWF 611

FIG. 3 SPECIFICATIONS FOR RESEARCH ON CIRCULAR SAWS



Deutsche Normen

Fräsmaschinen

Überwurfmuttern für Spindelköpfe

Holzbearbeitungsmaschinen

DIN VDH 3

Maße in mm



Bezeichnung einer Überwurfmutter mit Spindelgewinde W 39 × 1/8":

Überwurfmutter W 39×1/8" VDH 3

| $d_1$ Spindelgewinde | $d_2$ Gewinde | $d_3$ | $d_4$ | t | Für Spindelkopf |
|---|---|---|---|---|---|
| W 39×1/8" | R 1" m Sp | 65 | 40 | 5 | 40 VDH 2 |
| W 48×1/8" | R 1 1/2" m Sp | 80 | 50 | 6 | 50 und 60 VDH 2 |

Gewinde: Whitworth-Feingewinde 2 nach DIN 240
Whitworth-Rohrgewinde mit Spitzenspiel nach DIN 260

Werkstoff: St 60.11

Spindelköpfe an Fräsmaschinen siehe DIN VDH 2
Frädorne siehe DIN VDH 4 und 5
Messerdorne siehe DIN VDH 6
Hakenschlüssel siehe DIN VDH 10

Oktober 1927 Verein Deutscher Holzbearbeitungsmaschinen-Fabriken

Alleinvertrieb der Normblätter durch Beuth-Verlag GmbH Berlin S 14

FIG. 2 GERMAN STANDARD FOR SPINDLE CAP NUTS OF SHAPERS

experiments are then made in various factories. The sub-committee gathers, coordinates, and classifies the data of the experiments, sometimes being assisted in this work by the universities and *Technischen Hochschulen* (technical colleges). The results are then printed and distributed to all interested parties. These data do not relieve woodworking engineers from the necessity of doing their own research work. Rather, they supply bases from which to start. On the other hand, as is generally known, if one should ask five different foremen concerning the best shape of tooth for a certain kind of wood with a given moisture content, he would get at least six different answers, probably all of them more or less erroneous.

Another task of this committee is to settle the terminology, i.e., coin names for different methods and materials which can be universally understood. This very delicate work is much appreciated by those who have to write about woodworking and have to address an audience scattered all over the country.

The Unterausschuss für Lieferungsbedingungen in der Holzindustrie (Sub-Committee on Specifications for Raw Materials in the Wood Industries) is publishing, e.g., *Lieferungsbedingungen für Haut-, Leder-, Knochen- und Mischleim* (Specifications for Animal Glues), and is preparing specifications on soft and hard woods.

Der Unterausschuss für Arbeitszeitermittlung in der Holzindustrie (Sub-Committee on Time Studies in the Wood Industries) is making time studies on woodworking machinery and methods, thus supplying data for the precalculation of, say, a certain piece of furniture, the proper piece-work rate to employ, etc.

Fig. 4, which has been taken from Dr. Oswald Beck's *Die Stückzeitberechnung für Holzbearbeitungsmaschinen* (Time Studies on Woodworking Machinery), published under the auspices of the Sub-Committee on Time Studies, gives a number of curves showing the actual time consumed in boring holes of various diameters in hard wood. Special diagrams have also been drawn showing the time required in putting on and taking off wooden pieces of different sizes.

The Unterausschuss für Förderwesen in der Holzindustrie (Sub-Committee on Handling Materials in the Wood Industries)

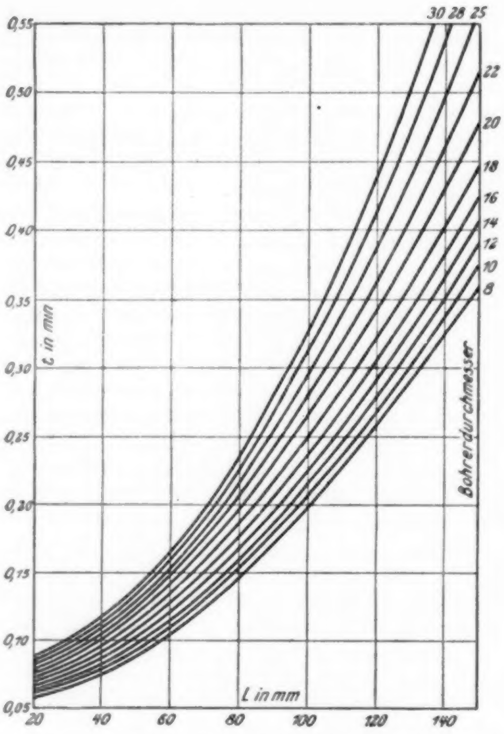



FIG. 4 CHART SHOWING TIME REQUIRED TO BORE HOLES OF VARIOUS DIAMETERS AND DEPTHS IN HARDWOOD

is investigating methods for handling logs in the saw mill, lumber in the yards, etc.

The results of the work of the RKW, with discussions of the various problems dealt with, are published monthly in the *RKW-Nachrichten* (RKW-News) and in the *AWF-Nachrichten* (AWF-News). Both journals may be obtained from the Nachrichtenstelle des Reichskuratoriums für Wirtschaftlichkeit, Berlin NW 6, Luisenstrasse 58.

Woodworking is no longer the cut-and-fit art it used to be. The evolution of the wood industries into engineering arts proceeds steadily, and as a result there comes a demand for cooperation, not only between the different branches of the wood industries of one country but between the industries of different countries, as e.g., the United States and Germany. It is the desire of the German committees to get in touch with those in America who are traveling the same roads, and the author would be very glad if this paper might contribute toward initiating such technical coöperation.

This short description of an important movement in the industrial development of Europe owes its origin to the interest of P. H. Bilhuber, Secretary of the Wood Industries Division of The American Society of Mechanical Engineers. The author is indebted to William Braid White, Chairman of the Wood Industries Division, for kind assistance in preparing this paper.

## GLOSSARY OF GERMAN TECHNICAL TERMS USED IN WOODWORKING

In order to render more intelligible Figs. 2, 3, and 4, the following glossary of German technical terms is appended:

*Abteilung.* Department.
*Anschrägwinkel.* Beveling angle.
*Art.* Kind.
*Auflockerungskoeffizient.* Factor showing increase of volume of the sawdust.
*Bemerkungen.* Remarks.
*Beobachter.* Observer.
*Betriebsleiter.* Superintendent.
*Bezeichnung.* Designation.
*Blattdurchmesser.* Diameter of blade.
*Blattstärke.* Thickness of blade.
*Feuchtigkeit.* Moisture.
*Firma.* Firm.
*Fräsdorne.* Mandrels.
*Fräsmaschinen.* Shapers.
*Freiwinkel.* Clearance angle.
*Güte der Schnittflache.* Quality of surface of saw cut.
*Gewinde.* Thread.
*Hakenschlüssel.* Hook spanner.
*Hartholz.* Hardwood.
*Holzangaben.* Wood specifications.
*Holzbearbeitungsmaschine.* Woodworking machine.
*Keilwinkel.* Angle of tooth point.
*Kreissägeblatt.* Circular-saw blade.
*Länge.* Length.
*L in mm* (Fig. 4). Depth of hole in millimeters.
*Lochbohren.* Drilling.
*Lückenfläche.* Tooth space.
*Maschinenangaben.* Machine specifications.
*Maschinenzeiten.* Cutting times.
*Maximale Schnitthöhe.* Thickest board to be cut.
*Maximale Schnittbreite.* Widest board to be cut.
*Messerdorn.* Mandrel.
*Photo.* Photograph.
*Riemenscheibe, Motor.* Pulley of motor.
*Riemenscheibe, Sägewelle.* Pulley of saw arbor.
*Riemenscheibe, Vorschub.* Pulley of feeder.
*Sägewelle.* Saw arbors.
*Schliff.* Kind of grinding.
*Schnittwinkel.* Cutting angle.
*Schnittgeschwindigkeit.* Cutting speed.
*Schnittbreite.* Saw kerf.
*Schränkung.* Width of set.
*Spanwinkel.* Hook of tooth.
*Spindelgewinde.* Thread of the spindle.
*Spindelkopf.* Spindle head.
*Spiralbohrer.* Twist drill.
*Stärke.* Thickness.
*Teilung.* Pitch.
*Tischmasse.* Measurements of table.
*t in min.* (Fig. 4). Drilling time in minutes.
*Überstand der Säge.* Projection of saw blade above board being cut.
*Überwurfmutter.* Cap nut.
*Untersuchungen.* Researches.
*Umdrehungen des Motors.* Revolutions of the motor.
*Umdrehungen der Sägewelle.* Revolutions of the arbor.
*Umdrehungen der Vorschubwalzen.* Revolutions of feed rollers.
*Versuch.* Experiment.
*Vorschub.* Feeding speed.
*Werkzeugangaben.* Specifications of tools.
*Zahnhöhe.* Height of tooth.
*Zähnezahl.* Number of teeth.
*Zweck.* Purpose.

# Discussion

PAUL H. BILHUBER.[2] It may be of interest to explain how this paper came to be written. One of the research projects of the Wood Industries Division has to do with standards for saws and knives. The committee organized to carry on that work has been busy on this large and comprehensive subject. It will submit a progress report at this meeting. In connection with this work, it seemed desirable to get information on the subject from other countries. The opportunity came last summer when a German engineer visited this country. He was identified with the governmental bureau which was to set up in Germany an organization to deal with questions of this sort. This engineer was Mr. Robert Schlueter, and he consented to write this paper, giving a brief outline of some of the work in Germany.

The paper will repay careful study because it is an example of work already done and work that will take some years to complete. A competent staff of experts is working on this project, but the very important and vital element which supports it is the German Government. The Germans are particularly interested in work of this nature because it is realized in Germany that the woodworking-machinery industry, in so far as design, output of machines, construction, electrification, and high rates of speed and feed are concerned, has as a result of the war lagged behind the progress made in other countries, notably our own and Sweden. With their accustomed thoroughness, the Germans are going hard after it, and they want to beat us if they can.

M. D. BALDWIN.[3] It may be postulated that any problem of standardization is attractive to the engineer. The engineer

[2] Assistant Factory Manager, Steinway & Sons, Long Island City, N. Y. Assoc. A.S.M.E.

[3] Vice-President, Oliver Machinery Company, Grand Rapids, Mich.

specializing in the application of his profession to the economical working of woods is no exception. The author states that in Germany sub-committees for the woodworking-machinery industry operate under general committees, in turn under the German national committee, for promoting industrial, commercial, and agricultural efficiency, and that these sub-committees are functioning today toward standardizing certain interchangeable parts of woodworking machinery, and that these committees are planning very extensive additional items for interchangeable manufacture. It is to this part of the report that the following remarks are directed.

It is not believed that any exception will be taken by any one on the efforts for research affecting cutting possibilities of saws, knives, boring bits, and the like.

In Germany, as in Great Britain and Europe generally, the development of woodworking machinery has followed quite different channels from the development here in America. In Europe materials are conserved while labor is cheap. In America materials are cheap and labor is high. Developing naturally along economical lines, under the circumstances, America has developed heavy-production and single-purpose machinery, whereas the European practice has evolved general-purpose equipment covering a multitude of uses.

The shaper in America has a function too well known to warrant description. The shaper in Europe, however, not only performs as a shaper as we know a shaper, but it is also equipped with sundry appliances making it a molder, a router, a tenoner, a flooring matcher, and what not. Again the hand jointer is as likely as not to be found in combination with a surfacer or thicknessing machine and so it goes.

It is difficult to see how the practice of standardizing particular parts within the woodworking-machinery industry, other than saws and knives, will confer a benefit commensurate with the effort of standardization.

A project which may be readily possible in a country of relatively small geographic size like Germany may be difficult of accomplishment in this large country of ours. In the United States where a machine purchased last November may be in the scrap heap tomorrow, due to the advances in the manufacturing art, such standards become limitations to efficiency as we understand the word.

In other words, the best thing for the purpose at hand is the American practice, rather than a compromise made in the interest of a theoretical advantage of interchangeability throughout the nation.

Finally, the engineer in the woodworking practice in this country is keenly favorable to research, the object of which is increased output, safety and convenience to the operator, quality, accuracy, and interchangeability of product, but he is little concerned with the infinitesimal returns to the industry theoretically brought about by standardization of machinery parts.

J. D. Wallace.[4] It requires no discussion in American engineering circles to prove that facts are more valuable than guesses in any industry. The progress made by Germany in industrial research is known to all, and the outline submitted by the author reveals an interesting alinement of his Government with technical organizations and industrial concerns which explains the widespread success of such enterprises in Germany.

The shortcomings of the United States along these lines are equally well known to us. In this country manufacturers cannot carry out a program such as outlined by the author, because our laws probably make the procedure illegal. It is a well-known fact that only the unofficial interposition of the Department of Commerce by Herbert Hoover has made possible the standardization enterprises which have recently been conducted in cooperation with various trade associations.

The present condition of each nation calls for neither excessive praise nor excessive recriminations; each proceeds on the plan dictated by its own requirements and economic position. Here in America we are highly individualistic and by temperament are skeptical of laborious research which our rapidly changing conditions may render obsolete before it is available for use.

There is need in Germany as well as here for original research as a basis for standardization; too frequently exhaustive tests are predicated on empiric figures which are anything but accurate. In the woodworking industries, as an example, no authoritative facts are known about the fundamental characteristics of wood sufficient for a proper starting point in the problem of its fabrication into useful commodities.

Woodworking is an old industry; so old that many of its processes have been handed down from grandfather to father and to son; and habits acquired before the age of scientific inquiry are hard to root out. Woodworking operations lend themselves easily to small-scale production, bringing into the industry numerous concerns too small to pay for expensive research. The material used is irregular in structure and lacks uniformity under various conditions of age and climate.

For these and other reasons the facilities of most research bodies in this country are taxed in the pressing business of securing highly specialized information that is only indirectly of fundamental value.

Despite the absence of a sound theoretical basis on which to work, American woodworking industries blunder through to successful results that are in nowise inferior to German achievements. We start out with the acknowledged advantage that in business a "doer" generally accomplishes a great deal more than a thinker. We prove the truth of the statement of our great philosopher Will Rogers that "one man digging is better than one hundred committees sitting."

The attention of our woodworking interests are today centered on the greater possibilities of saving by mass production and a wider extension of market. One thousand dollars spent for advertising or improved equipment will bring more profit than the same amount of money spent in research under present conditions, and it is likely this condition will continue until our economic situation changes greatly.

The author rightly says, "Woodworking is no longer the cut and fit art that it used to be." We could well afford to exchange with Germany some of the individualistic products of our genius for the stabilizing results of their profound research. To effect this exchange we have need of some agency to provide authoritative translations, because at the present time the subject matter of German publications is practically unavailable to the ordinary American manufacturer.

The Wood Industries Division could perform a valuable service by formally accepting the invitation of the author to cooperate, to make frequent translations of the material specified in his paper, and to distribute it generally among engineers of this country.

[4] President, J. B. Wallace & Co., Chicago, Ill. Mem. A.S.M.E.

# Automatic Production of Small Wood Parts

By I. B. Whinery[1] and G. A. Whinery,[2] Grand Rapids, Mich.

*The authors point out that more attention has been given to the design of hand-fed and manually controlled general-purpose machinery for woodworking than to the building of automatic machines. Among other reasons it is shown that the set-up time is generally long as compared with the working time because of the rapidity with which wood can be worked.*

*As examples of automatic woodworking machines the authors describe three: (1) A knob-tapping machine, chosen to show how production may be increased by performing a single operation more rapidly than the best operator could do it by hand; (2) a square-knob blanking machine to illustrate the combination of several distinct operations in one mechanism; (3) a rosette machine as an example of one the primary purpose of which is to achieve quality without sacrificing speed.*

*The economic principles involved in the use of automatic woodworking machinery are discussed in the remainder of the paper.*

For a number of very apparent reasons, woodworking machine builders have given much more attention to the design of hand-fed and manually controlled general-purpose machinery than to the building of automatic machines. In general, metal-working machinery builders have found many more applications for the automatic principle than have builders of machines to work in wood.

One reason for this is the relatively small number of wood parts required to be manufactured. With the exception of matches and toothpicks, which are not, strictly speaking, wood parts, there is no article made of wood the production of which approaches in quantity that of such items as screws, bolts, nuts, nails, and a number of other metal parts which might be enumerated.

Another contributing factor to this situation is the fact that even by means of unspecialized machinery, operated manually, wood parts can be produced relatively rapidly. With so elementary a machine as an ordinary hand turning lathe, simple wooden turnings can often be produced more rapidly than the same shapes could be turned out of metal in an automatic metal-working lathe. Due to this, it is more difficult to save enough time with an automatic woodworking machine to make it a good investment than in the case of a machine for working in metal.

A corollary to the rapidity with which wood may be shaped on simple machines is the relatively long period required to set up an automatic wood-turning machine in comparison with its running time. Unless a considerable number of parts can be run at one set-up, it often takes less time to produce the parts on general-purpose woodworking machinery than to set up an automatic machine.

However, it must not be concluded that the automatic field has been entirely neglected by the machine builders. There are standard machines on the market for the production of such turnings as dowels, insulator pins, clothes pins, spools, and bobbins. Wedges are now made by means of automatic machinery, and a number of machine manufacturers build automatic feeding mechanisms which can be incorporated in shapers and other woodworking machines, lending themselves readily to the production of small wood parts.

[1] Manager, Waddell Manufacturing Co. Assoc-Mem. A.S.M.E.

[2] Superintendent, Waddell Manufacturing Co. Jun. A.S.M.E.

Presented at the Third National Meeting of the A.S.M.E. Wood Industries Division, Grand Rapids, Mich., November 26 and 27, 1928.

The basis of the material to be presented in this paper is a group of automatic machines which have been developed for the manufacture of wood ornaments for furniture. They are interesting because there are a number of factors to be considered in connection with machinery of this type which do not exist in the better-known types of automatic machines, such as automatic turning machines of various kinds.

The machines which have been selected for discussion in this paper are taken as typical machines; that is, they illustrate principles which apply to automatic woodworking machinery as a whole. A knob-tapping machine has been chosen to show how production may be increased by performing a single operation

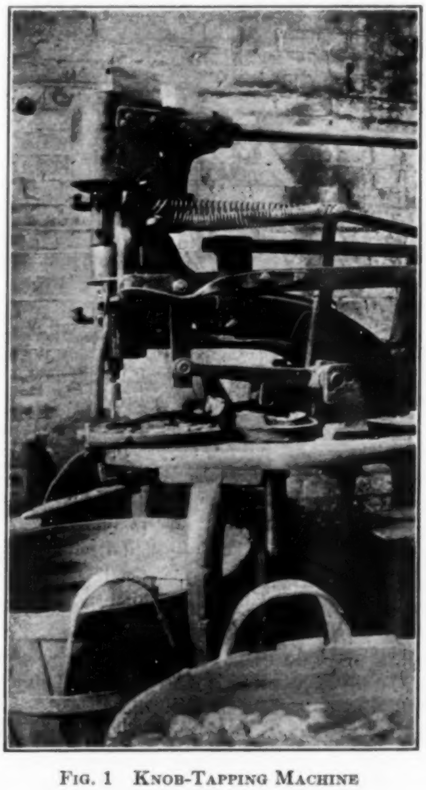


Fig. 1 Knob-Tapping Machine

more rapidly than the best operator could do by hand; a square-knob blanking machine illustrates the combination of several distinct operations in one mechanism; and a rosette machine is an example of a machine the primary purpose of which is to achieve quality without sacrificing speed.

### Knob-Tapping Machine

An example of an automatic machine which performs only one operation, but does that one much more rapidly than could be done by hand methods, is the knob-tapping machine illustrated in Fig. 1. Fig. 2 illustrates the operation this machine performs. Round knobs are furnished to the machine with the screw-holes bored, but not tapped. The operator places them in holes which are spaced around a horizontal disk and which are just large enough to allow the knobs to drop in easily, with the hole up. A cam operates a finger which indexes the disk so that

each hole stops directly underneath a vertical tap. The spindle on which this tap is located rotates and moves up and down at the same time, the mechanism being so arranged that during the descending stroke the tap tends to screw into the knob and during the rising stroke the tap revolves in the opposite direction. The speed with which the tap moves up and down is regulated according to the lead of the tap.

When the machine is in operation, the attendant places the untapped knobs in the holes in the disk as they come past his

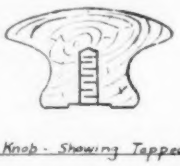



FIG. 2 SECTION OF KNOB SHOWING TAPPED HOLE

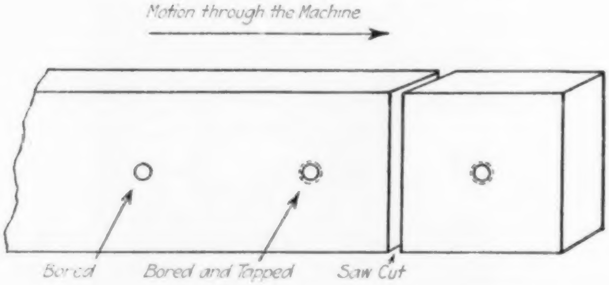



FIG. 3 STEPS IN MAKING SQUARE-KNOB BLANK

side of the machine. The machine indexes the disk around, one hole at a time, bringing each knob directly underneath the tap and holding it there until the tapping operation is completed. As each knob stops to be tapped, a jaw swings against it from one side, clamping it to prevent its turning with the tap. A little further on in the circle is a hole underneath the disk through which the tapped knobs drop into a receptacle. A pushing rod fastened to the spindle frame and moving up and down with it pushes out of the disk any completed knobs which may fail to drop out of their own accord.

This machine is relatively simple in its construction, but it performs the tapping operations at least twice as rapidly as could be done by hand. Instead of having to perform a number of movements, the operator is relieved of all motions except placing the untapped knobs bottom side up in a hole in a plate.

### SQUARE-KNOB MACHINE

The next type of automatic machine to be discussed is one in which several operations are performed by one machine. An example of this is a machine for cutting sticks into square blocks, each having a bored and tapped hole part way through its center. Blocks of this kind are used as blanks for square knobs, such as are used on mission furniture, and the process is illustrated in Fig. 3. The machine for doing the work is shown in Fig. 4.

Stock coming to the machine is in the form of sticks planed on both sides and ripped to uniform width. The operator starts a stick through the machine on edge, that is, with the planed sides vertical, after which the piece is carried through the machine by means of the feed mechanism.

Three tools are mounted on a carriage which oscillates at right angles to the direction of the stick, a drill, a tap, and a circular saw, all in line. The feed first pushes the stock so that the end is opposite the drill and remains motionless while the carriage moves in and the drill bores the hole. After the carriage has moved back from the work, the stock is indexed automatically, bringing the hole which has just been bored opposite the tap and presenting a new section to the drill. On the following inward movement of the carriage, the first hole is tapped, while a new one is bored. The last operation of the series consists of cutting off the block with the saw and discharging it into a receptacle underneath. Once the series of operations is started, it is automatic and continuous, a block being drilled, tapped, and cut off at each stroke of the carriage.

On account of the tapping operation, the carriage must move in and out at a speed which will allow the tap to cut a clean thread and the tap must be reversed when it reaches the bottom of the hole. This is accomplished by feeding the carriage back and forth with a reversing screw mounted on the same shaft with the tap. Power is supplied from a countershaft by means of belts.

It is conceivable that each of the operations performed by the machine just described might be done as rapidly by means of simple machines operated by hand. However, much greater production is possible per operator when the three tools are combined in one mechanism.

### ROSETTE-CUTTING MACHINE

Automatic machinery is often thought of merely as a means of speeding up production. However, it may sometimes be used primarily to turn out work of a higher quality than hand

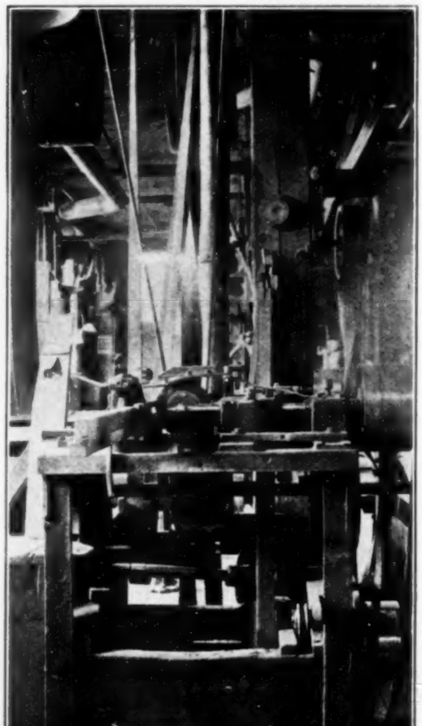


FIG. 4 SQUARE-KNOB MACHINE

methods, although it should be mentioned that production is very likely to be increased incidentally. A machine the main purpose of which is to benefit quality is the rosette-cutting machine. Its function is to cut a rosette in the face of a stick of lumber, a subsequent process releasing the rosette from the stick. The piece to be produced is shown in Fig. 5, and the machine in Fig. 6.

The machine uses as a foundation a standard high-speed

shaper, which has been changed into a special-purpose machine by the addition of special attachments. The top of the spindle has been cut off and threaded to receive a chuck for holding rosette knives. The standard screw mechanism for raising and lowering the spindle has been removed and a cam and pedal have been mounted underneath. The pedal raises the spindle for purposes of trial during the set-up, whereas the cam gives it an oscillating movement during the production period. The rotating knives are thus raised and lowered through a hole in the table, over which is placed the stock to be cut. A shoe mounted above the hole presses the stock down tightly against the table while the knives cut the stock from below.

Attached to the shaft operating the cam which raises and lowers the spindle, and timed with it, is another cam which controls the stock-clamping shoe just described. A feed mechanism is also operated from this same shaft by means of bevel gears and universal joints and indexes the stock forward between cuts. One stick is fed into the machine after another, the mechanism pushing them under the shoe, where they are clamped and cut as the spindle rises and are pushed along the diameter of the cut between strokes. The sticks are supplied to the machine in random lengths and the operator has time not only to feed the machine, but to saw out knots and other imperfections in the lumber with a handsaw before starting the sticks through the machine.

The outstanding feature of the rosette-cutting machine is the fact that the rise of the revolving knives into the wood is controlled mechanically and therefore accurately. The same operations could be performed on a manually operated machine with about the same speed, but it would be practically impossible to find an operator who could make all the strokes in exactly the same way, neither burning the wood by pushing the revolving knives into it too slowly, nor tearing it out by too rapid a cut.

### Economic Principles Involved

As stated before, the machines just described have been taken as types. They are not models of machine design nor of workmanship, having been built out of materials at hand by a factory

Fig. 5 Cross-Section of Rosettes Cut in Stick

millwright. However, they illustrate some of the principles involved in the design of automatic woodworking machinery as well as the fact that standard machines may be converted into single-purpose automatic machines by the addition of special attachments.

The rosette-cutting machine is built to meet requirements which do not usually have to be met by the standard automatic machines generally shown in manufacturers' catalogs. It must be able to do satisfactory work with all the ordinary kinds of cabinet woods, regardless of grain and texture. Clothes pins, spools, dowels, and most of the small parts for which standard machinery is made can be manufactured out of any wood which happens to combine strength, cheapness, and workability. The rosette-cutting machine not only has a larger variety of materials to deal with, but must turn out a product which is much smoother in finish than articles of a more practical nature.

Another factor present in the design of the machinery which has been described is the relatively short duration of the production period after the machine has been set up. Ten or twelve hours on one pattern is a high figure and one or two hours per set-up represents more nearly the average. For this reason, it is often necessary to sacrifice speed in production in the interests of rapid set-up.

In the opinion of the authors, there are a number of applications for automatic machinery in the woodworking industries which have not been developed. However, they believe that most of these applications are so isolated that the solutions are special machines for special operations rather than attempts on the part of the machinery manufacturers to turn out vastly increased lines of standard automatic machines. The most logical manner in which to develop an automatic machine is

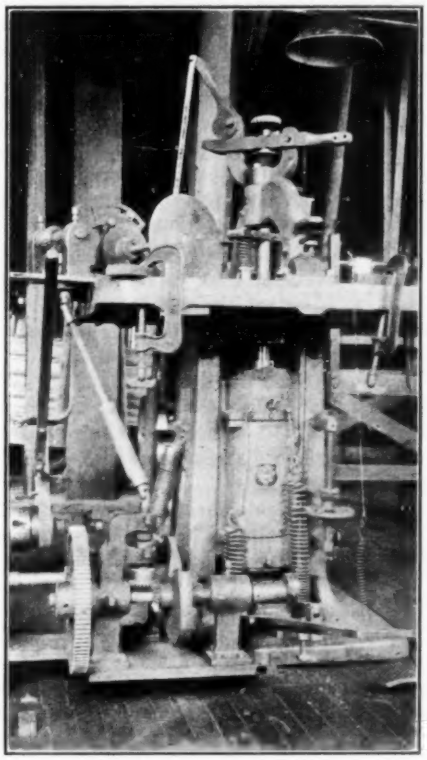


Fig. 6 Rosette-Cutting Machine

often found to be the application of special attachments to a standard machine.

Unless a comparatively large number of special machines are to be built, the cost of special patterns and the machining of special castings in small lots is unduly expensive if it is possible to adopt a standard machine for the purpose at hand.

When choosing the type of machine that will best perform a certain operation or group of operations, every method of working in wood should be considered. For instance, a lathe is not necessarily the best machine for producing a turning. A modified shaper may be able to handle the work much more efficiently, as in the case of the rosette-cutting machine. Among the less common processes of working in wood that should be taken into consideration are embossing with hot dies and shearing with cold dies somewhat similar to those used on metal punch presses.

After the type of machine has been decided upon, the machine designer must weigh ease of set-up against the number of pieces the machine is to produce per hour after production starts. Due to the rapidity with which wood may be worked, the set-up time problem assumes larger proportions than in the case of machinery for working harder materials.

The rosette-cutting shaper just described may be compared with a type of machine which is sometimes used for the manufacture of rosettes, consisting fundamentally of two cutting heads and a splitting saw. The heads are mounted opposite each other and oscillate back and forth on either side of the stock,

approaching and receding from each other so that they cut rosettes into both sides of a stick that is fed on edge between them. The stick then passes through the saw, which cuts out the center of the stock and allows the rosettes to drop out on both sides.

A machine of this type is obviously theoretically capable of turning out more work per hour than the modified shaper, inasmuch as two cuts are made per stroke instead of one. It is excellently adapted for long runs at one set-up.

In the case of shorter runs per set-up—for instance, one thousand or twenty-five hundred pieces of a pattern—the authors consider the simpler automatic machine to be preferable. When the running time per job is in the neighborhood of an hour, a difference of ten or fifteen minutes in the set-up time is very important, and the time saved in setting up a simple machine may often overbalance the increased production of a more complicated mechanism. The authors do not wish to disparage complicated machines, but merely to point out that set-up time should be considered as well as production.

Another factor to be considered in the design of automatic machinery is the quality of work to be produced. Increased production can often be achieved at the expense of quality. However, as a general principle, automatic machinery is more likely to turn out work of a high quality than hand methods. Mechanical feeds can be so designed as to move rapidly when no cutting is being done and to slow down at the proper instant to give a smooth finish. The manual skill of an experienced workman may often be built into a machine whose operator is to be merely an unskilled attendant.

In the consideration of automatic machinery, attention must be given to the economic side. The machine with the greatest capacity is not necessarily a good investment unless there is enough work at hand to keep it busy a large portion of the time. The cost of the machine must always be balanced against the savings it will make in labor, throw-outs, etc., and the possibility of not being able to keep the machine busy must be borne in mind. This self-evident condition is sometimes overlooked by enthusiastic machine designers and often by enthusiastic machinery salesmen.

The spectacular characteristic of automatic machinery is its increased capacity over hand methods. As has been explained in this paper, increased capacity may be achieved either by performing one operation more times per minute or by performing several operations at once, or by both methods. Even where the actual cutting operation cannot be speeded up, a mechanism can often be built to move the stock more rapidly between strokes and to avoid lost motions likely to occur when hand feeds are used.

Often when no attempt is made to turn out more work than could be produced by a good operator using hand methods, surprising increases in production may result from automatic methods. When the rosette-cutting shaper, described in this paper, was first put into operation, the feed mechanism was adjusted to give the same number of strokes per minute as were made by an experienced operator on a foot-pedal machine. To the surprise of every one, the output of the machine per day was found to be about twice that of the older machine. An analysis of conditions revealed a number of reasons for this:

In the first place, the automatic machine made the same number of strokes per minute at four-thirty in the afternoon as at seven-thirty in the morning. There was no human fatigue to contend with. Furthermore, not having to concentrate on mere mechanical movements of his arms and legs, the operator found time to inspect the stock as he fed it into the machine and to saw out defective parts, thereby reducing the number of throw-outs leaving the machine. A third reason for the increased output is the fact that the automatic machine produces more pieces per sharpening of the knives, and consequently there is less time lost in keeping the knives in shape. Due partly to the fact that the operator can cut out the knots from the stock before they reach the knives, and partly to the fact that the knives are always fed into the stock uniformly, they stand up appreciably longer on the automatic machine. The authors feel that some increase in production is almost sure to result from a change from hand to automatic methods, even when it is not the primary consideration in making the change.

## Discussion

Carroll A. Ross.[3] We have built some automatic machines, and we find generally that in every operation there is one limiting operation. For instance, on the rosette-cutting machine the speed at which the knife can approach the work is probably the limiting factor. The rest of the operation—the moving of the stock, which is so very light that it can be moved with great rapidity—can be accomplished so that the cutting tool can actually be cutting a large part of the time.

Thomas D. Perry.[4] Frank Gilbreth said to me some years ago, as he went through some of the factories in Grand Rapids, that he felt there was a tremendous need to apply automatic methods to repetitive woodworking operations. It was a field very greatly neglected, he felt. He was referring not only to the making of small parts by automatic machinery, but to the automatic feeds of various types that could be and some of which since have been applied to various woodworking-machine operations.

Monte B. Gathman.[5] Mr. Perry probably does not realize how much automatic machinery there is in this country. Many of the larger concerns maintain departments for the development of automatic machinery; other progressive concerns have these ideas developed by small machine shops over the country. The authors show three or four machines they have developed; Mr. Ross has developed others; Fisher Body Corporation has developed many automatic machines. These machines as a rule cover specific operations, not applicable for general use, but the total would reach a sizable figure.

An automatic shaper has been designed that will do the work of two double-spindle shapers; it takes up less floor space than the two machines it replaces and takes the danger away from the operator and much of the hard work.

David Turcott.[6] We have had some requests to build automatic machinery. Automatic machinery is undoubtedly coming, and we intend to follow the demand in developing it. So far, the demand has been only for special automatic tools for which there is a very limited market. The demand for automatic machinery will increase rapidly as soon as manufacturers of wood products are forced by competition to use it.

M. Everett Dick.[7] We once built an automatic shaper for making brush handles. It had six spindles with automatic feed and seven motors—two to make the side of the handle, two spindles to make the inside curve, two to make the outside curve, and another motor for the feed. This is what we are up against

[3] Piqua Handle & Mfg. Co., Piqua, Ohio. Assoc. A.S.M.E.

[4] Director, Woodworking Division, Bigelow Kent Willard & Co., Inc., Boston, Mass. Mem. A.S.M.E.

[5] Manager, Plant 33, Machine Design, Fisher Body Corporation, Detroit, Mich. Mem. A.S.M.E.

[6] Yates-American Machine Company, Beloit, Wisc. Assoc-Mem. A.S.M.E.

[7] Buss Machine Works, Holland, Mich.

in the manufacturing of automatic machinery. What are the prospects of getting an order for a second machine?

We have made a great many automatic machines successfully, and I am a believer in making woodworking machines as fully automatic as possible, removing the human element absolutely, because it is going to help to standardize the product.

That machine for automatically making brush handles among other things eliminates many different styles of brush handles. With more automatic machines, fewer varieties will be made, but more of one particular design.

Manufacturers of woodworking machinery want the users of it to explain their problems before the machine is bought so that the designing may be worked out together.

M. D. Baldwin.[8] Those in the wood industry probably have a considerably exaggerated idea of the business and the importance financially of the machinery builders. Exclusive of the sawmill manufacturers there has not been a year since statistics have been available, and that covers a period since 1918, in which the manufacturers of woodworking machinery have done a gross volume of business exceeding $20,500,000, while the total yearly business of the wood industries is about $4,000,000,000. Thus it is evident that the manufacturers of woodworking machinery have little available capital and little interest in attacking these specialized problems of the woodworking industry.

There are any number of factories working in wood which have an individual volume in excess of the total volume of the manufacturers of woodworking machinery. Consequently, we are able only to approach this building of special machines as agents of those who have foresight and are willing to attack problems and pay a return commensurate with the effort put on the first machine.

I recall a machine built for the General Electric Company. They were willing to pay the expense necessary to develop a wedge cutter. Subsequently they ordered another. We are going to make money on the second machine. The General Electric Company will pay for the machine in four to six months from the savings it effects; the only profit we can make is what we may make out of the one or two machines that can be sold.

The wood industries have a tremendous volume of business. The manufacturers of machinery do not turn over their capital invested more than one and a half times a year. This is an indication of the amount of investment necessary to produce that $20,500,000. This is an angle which few have considered. I bring it up in no sense of complaint. We are proud of our position. We have helped the wood industries to make progress, and you in turn have given us money to live on. Nevertheless, it takes funds to develop new and special machines. We are willing and glad to do it, and some of the big firms have acted handsomely in helping out on these special problems. There are many smaller firms that need the same sort of automatic equipment, but that are not willing to carry on far enough to put it across.

Armen S. Kurkjian.[9] Nothing has ever been accomplished without the cooperation of the user and the manufacturer. It is the user who sees certain needs in his particular field and puts himself immediately in touch with the manufacturer who may assist him in the production of a machine to do that particular work. He soon finds that cooperation gets him very good results.

As a concrete example, Mr. Gathman came to Grand Rapids one day with some problems in his mind. He outlined certain things that they were doing and that should be changed; things that ought to be done automatically so as to save time. The result was that we developed a machine, now in operation, that with one man can do the work formerly done by four machines with one man each, or four men. That is a ratio of one to four in direct labor saving, and of course the floor space saving also is considerable.

Mr. Baldwin mentioned the instance of the wedge-cutting machine for the General Electric Company. That again was the result of cooperation—of studying the problem and meeting the need.

The automatic shaper that was developed was without a question the result of cooperation. The automatic rosette-cutting machine was the direct result of cooperation.

Cooperation between the fabricators of wooden parts and the woodworking-machinery manufacturers will assist both 100 per cent, and the net result will be that the fabricators of wood will get the greater good out of it because the returns will be continuous to them.

Many of the larger woodworking companies have their own experimental research department, which does evolve certain machines for their particular needs. What will take them about two years to design and to put in actual practice will probably take not to exceed three months for the well-organized woodworking-machinery manufacturer who already has a corps of engineers well trained for such work.

### Authors' Closure

The representatives of the machinery manufacturers who have discussed the paper confirm the opinion of the authors that the building of special automatic machinery is not a very profitable business for the machine builders. However, there seems to be a concensus of opinion that such machines may often be a very good investment for the user of the machine, and several of the machinery representatives have suggested that the users of machinery should place such problems before them.

While this procedure would undoubtedly accomplish much, still it might also be to the benefit of the machinery manufacturers to devote some effort to educating users to the value of automatic machinery in general. In other words, since the user must ultimately bear the cost of developing special machinery, it might pay the machine manufacturer to make his customers see how much to their advantage such special machinery would be.

It seems possible that the cost of special machinery might be reduced somewhat below the prices usually quoted by more often working out feed attachments, etc., rather than by building special equipment from the ground up.

Furthermore, in view of the number of different electrical frequencies above 60 cycles now being used in connection with woodworking machinery, the cost of a frequency changer to be used with a special machine is often an item of considerable expense. A number of different makes of routers are operated successfully on 60-cycle current, using belts or friction drives to obtain speeds as high as 20,000 r.p.m. Since a special machine is always rather high in first cost, anything that can be done to make it less expensive should encourage its development, and there are surely some occasions on which the frequency changer might be dispensed with for the sake of lower first cost. The savings made possible by the use of an automatic machine will usually justify its use even though its design is not as finished and its appearance not as trim as those of a standard general-purpose machine.

[8] Vice-President, Oliver Machinery Co., Grand Rapids, Mich.

[9] Sales Manager, Oliver Machinery Co., Grand Rapids, Mich. Assoc-Mem. A.S.M.E.

# Obtaining the Maximum Fuel Value From Wood Waste

## Amount of Lumber Wasted in Average Woodworking Establishment—Arrangement of Boiler Plant for Efficient Utilization of Wood as Fuel—Installations for Special Conditions—Avoidance of Gas Explosions in Furnaces and Shavings Pipes

By E. WINHOLT,[1] MOLINE, ILL.

IN THE lumber industry there is a considerable amount of waste from the time the lumber is out on the ground until it leaves the factory as a finished product. It would be hard to estimate just how large a percentage the waste is, but it may safely be assumed that not less than 50 per cent of the lumber is waste in one form or another.

In the sawmill operations, where the logs are turned into dimension lumber, the waste consists mainly of trimmings, ends, bark, and sawdust. All of these leave the sawmill and are generally used for fill in low lands, except a very small percentage which is burned under the mill boilers in the form of sawdust.

Sawmills are generally located far from any market where such waste could be sold, and as it contains a considerable amount of moisture, it would not pay to ship it. There is therefore not much that can be done in salvaging such waste.

After the lumber has been shipped to the sawmills and the lumber yards either operated in connection with wholesale or retail business, or located and used for storage for manufacturing purposes of different kinds, there is again a large waste, but this time it is near a market and the lumber is in a far drier state than obtained at the sawmill.

### Waste of Lumber in Average Factory About 25 Per Cent

In factories such as planing mills, woodworking establishments, or other enterprises where the lumber and rough stock are worked into the finished product, the waste amounts to not less than 25 per cent of the total lumber. In these cases the sawdust, shavings, and often the trimmings and the mill wood are burned under the boilers to supply power for the industry, and some of their fuel value is obtained in this manner. Where more refuse is available than can be used in this way, it is sold in a general market to be used for kindling wood, mainly for household purposes.

It may be stated in passing that a wagon factory manufacturing a regular line of farm wagons found that for a finished wagon weighing 1200 lb. there was produced from the lumber used for each wagon 240 lb. of shavings. This information was arrived at by two different methods:

*a* Weighing the shavings delivered to the boiler room when factory was working on 100 wagons per day.

*b* Checking the dimensions of each piece of lumber which was used in the manufacture of one wagon and again checking the dimensions of the finished part.

It is evident that by utilizing the wood refuse in an efficient manner, a decrease in the cost of the fuel is effected and a corresponding amount of coal is left in the ground, in which way natural resources are conserved. Such wood should therefore so be burned that the greatest possible amount of heat is obtained from a given quantity. This, however, is not the case. Generally, it is considered that just because the wood refuse must be disposed of and does not cost the factory anything, the efficiency of its combustion is of no importance.

However, there are today plants where planing mills and sash-and-door works are now supplying their entire requirements for heat, light, and power from sawdust and at the same time selling the mill wood and trimmings for domestic use. In such cases the installation for obtaining this result has proved an excellent investment. What has been done in some of these factories can be accomplished in practically all of them, provided the management will take steps to have the installation brought up to date, and will utilize the best talent and mechanical equipment obtainable.

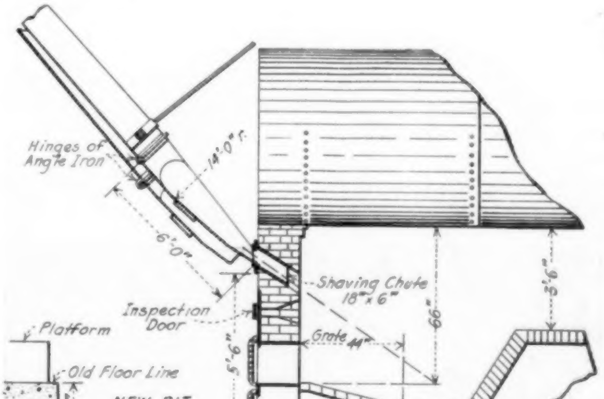


Fig. 1 150-Hp. Horizontal Return-Tubular Boiler Arranged for Burning Shavings

There are a large number of places where wood refuse is burned in an inefficient manner, and where coal has to be supplied in addition. Where such is the case, the coal is generally hand fired at the same time the shavings are admitted from shavings systems overhead, or possibly also fired by hand. There is no question that shavings mixed with coal screenings make a good fuel which burns readily, but sight is entirely lost of the fact that the furnace and the firing methods which contribute to high efficiency on the wood are not at all suitable for the burning of coal, and vice versa.

### Arrangement of Boiler Plant for Efficient Utilization of Wood as Fuel

It has been proved by actual tests that where more than one boiler is operated it is far more desirable to operate one or more of them on shavings, and should the amount of steam produced be insufficient, then to operate one or more on coal, thereby operating both of the two groups at maximum efficiency.

In burning any kind of fuel under a steam boiler, the purpose is to produce the largest amount of steam from a given quantity

[1] Deere & Co.

Presented at a meeting of the A.S.M.E. Wood Industries Division, Grand Rapids, Mich., November 26 and 27, 1928. For discussion see page 33.

of fuel. The ratio between the two is generally called the rate of evaporation, and may range from 1 to 5 lb. for shavings and from 4 to 9 lb. for coal. The more pounds of steam produced with a pound of fuel, the higher the efficiency.

In a test carried out in a plant where for a long period of years both shavings and coal were burned together, it was found that less than 2 lb. of steam was produced per pound of shavings; whereas when the shavings were burned alone in boilers suitable for the purpose, approximately 5 lb. of steam was produced from 1 lb. of dry shavings. This test indicated that for a long period of years a great waste had been taking place in the combustion of the wood and refuse, which had to be made up by the burning of coal in order to take care of the demand for steam.

In arranging a steam boiler for the efficient utilization of wood as fuel, the prime requirement is furnace volume. A good ratio is one cubic foot of furnace volume for each developed horsepower. Or, in other words, if a 500-hp. boiler is installed and it is desired to obtain 1000 hp. from it, the furnace volume should be not less than 1000 cu. ft.

It has often been stated that wood refuse such as shavings should be dropped by gravity on the grate, and that all the air required should be admitted through the grate. This, however, does not hold in the case of dry wood shavings or refuse, as here the proposition is mainly one of surface combustion. Only a very limited amount of grate surface is required, but air should be admitted over the fire either along with the shavings or separately.

The simplest method is to introduce the shavings through a spout from the cyclone leading through the front of the furnace wall, and to use a Dutch oven setting where a flat suspended brick arch is hung over the furnace and reflects the heat of combustion down upon the shavings in the furnace. Following this arrangement, the fine shavings are burned in suspension when entering the hot furnace in a manner very similar to that employed in the combustion of pulverized coal. The shavings which do not burn in suspension are carried by the air and their momentum down on to the grate, where a small pile is formed which is burning around its edges and on the surface due to the air introduced with the shavings.

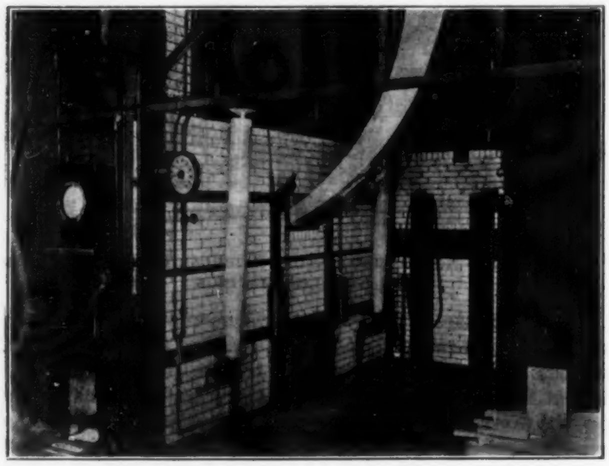


Fig. 2 Front of 344-Hp. B. & W. Water-Tube Boiler for Burning Shavings, Refuse, and Scrap Wood

While a fairly good draft is required to burn coal because of the thickness and density of the fuel bed, the opposite is the case with dry wood shavings. Under the conditions above stated, boilers operate very satisfactorily with drafts over the fire ranging from 0.05 to 0.20 in. The complete combustion takes place in the furnace and in the front tube section, and practically no combustible is carried over into the rear pass.

A boiler operating in this manner may run for six to twelve months without cleaning out the ashes from the rear pass; whereas, when shavings were burned together with coal, the half-burned wood particles would fill the rear end of the boiler and the smokestack in a very short time.

Wood refuse is a very desirable fuel when handled in the proper manner and is to be preferred in all cases over coal. It makes a very hot fire and will start a boiler up from cold in a very short time; also, when operation is to be discontinued, the shavings in the boiler may be burned out in a few minutes and the boiler may be left safely until operation is again commenced.

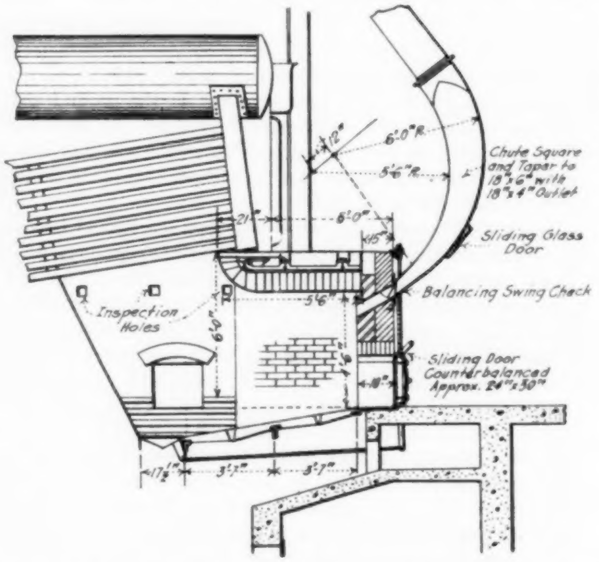



Fig. 3 250-Hp. Water-Tube Boiler Rebuilt With Dutch Oven for Burning Shavings

Besides wood shavings and refuse from the wood shops, there is a large amount of scrap wood, boxes, barrels, kegs, etc., to be disposed of in the average industrial establishment every day, and in place of loading all this on a wagon and hauling it to a convenient dumping place, it is good economy to burn it under boilers equipped for that purpose and for the burning of shavings. In spite of this, however, many industrial establishments maintain a continuous bonfire in their back yard and at the same time pay a high price for the fuel they burn under the boilers.

### Installations for Special Conditions

Fig. 1 shows a 72-in. × 18-ft. horizontal return-tubular boiler arranged for burning shavings from the shaving system and scrap wood by hand firing. The grate is a single herringbone-type bar 44 in. long and the width of furnace at the grate line is 5 ft., thus making a total grate surface of 18 sq. ft. The distance from the grate to the shell of the boiler is 66 in. Between the rear end of the grate bar and the bridgewall is a level ledge 2 ft. in length to provide for the accumulation of shavings and form a pile at all times covering the rear of the grates solid. This pile of shavings acts as a heat-storage or heat-equalization medium. The flow of the shavings is directed on to this storage arrangement. This boiler, which is rated at 150 hp. will without difficulty develop 200 hp. No spreading, raking, or other disturbance of the fuel bed is permissible.

Fig. 2 shows the front of a 344-hp. B. & W. water-tube boiler.

The setting height, measuring from the floor line to the bottom of the front headers, is 8 ft. This boiler has no Dutch oven and only 44 in. length of grate bar, with a width of 6 ft. at the grate line; the furnace width is 8 ft. Between the rear end of the grates and the bridgewall is placed a double dumping grate 27 in. long, thus making a total grate surface of 28 sq. ft. and a total furnace volume of 455 cu. ft. The grate is placed at the floor line and slopes toward the rear. A regulated door to admit air from the boiler-room tunnel to the under side of the grates is provided.

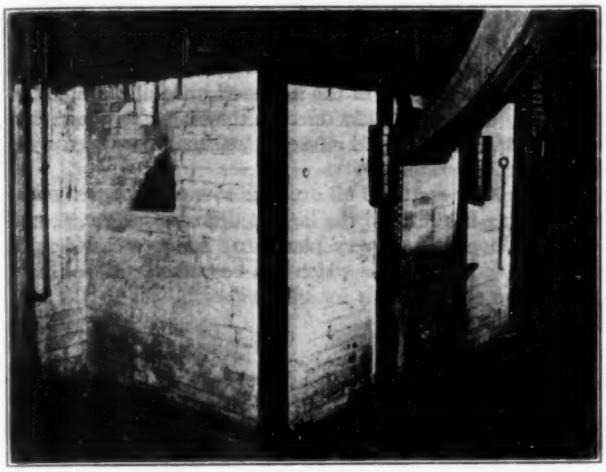


FIG. 4 VIEW OF FRONT OF BOILER SHOWN IN FIG. 3

The front has a 6 × 18-in. cast-iron 60-deg. chute with a balanced check valve for admission of the shavings and a 24 × 30-in. counterbalanced sliding door for the firing of refuse and scrap wood. On each side of the front door is placed an oil burner which is used when there is a deficiency of wood or shavings.

This boiler will produce 700 hp., in which case additional air must be admitted under the front door in order to eliminate heavy smoke. A flow meter and draft gage is placed in a prominent position on the front left corner and a $CO_2$ recorder on the side.

Figs. 3 and 4 show a 250-hp. boiler which was rebuilt from a stoker-fired setting, retaining, however, its low (5 ft. 6 in.) setting height. A Dutch oven was placed in front of the old setting and furnished with a flat suspended arch, shaving chute, and front door, the same arrangement as used under the previous boiler.

The grates in this furnace are 88 in. long and with a dump grate to the rear; the total grate surface is 47 sq. ft. This boiler has developed over 500 boiler hp.

Figs. 5 and 6 show a 363-hp. boiler which is an enlargement and improvement over the boiler shown in Figs. 3 and 4. The fact is that the 250-hp. boiler which was rebuilt in 1921 saved enough money on fuel cost to purchase and install this new 363-hp. boiler, and after its completion the 250-hp. boiler was scrapped because of the limited pressure allowed by the boiler insurance policy.

It is a new installation with a setting height of 12 ft. The grate length is 88 in. with a dump grate to the rear. There is an oil burner on each side of the front sliding door. The grate slopes 2 ft. downward; the distance to the Dutch oven is 10 ft., and the grate area is 50 sq. ft. The total furnace volume is 1030 cu. ft. This boiler has developed 800 hp. and should be capable of delivering 1000 hp. when sufficient fuel is available. This is a very successful setting for shavings, scrap, and factory refuse.

These two latter boilers have a peculiarity well worth mentioning and which is contrary to what would naturally be assumed. When this type of setting is hot and the rear of the grate has an accumulation of combustible on it with additional fuel entering from the shaving chute, the flame under the Dutch oven rolls forward under the arch and toward the front of the Dutch-oven wall. At this point the air and shavings from the chute strike the current, and force it downward and toward the shavings pile at the bridgewall.

At such times, when no fuel is fed to the boiler, the air emerging from the shavings chute is burning into the storage pile, which is evidenced by a hole in the pile in a straight line with the direction of the chute.

## AVOIDANCE OF GAS EXPLOSIONS IN FURNACES AND SHAVINGS PIPES

It may be asked how it is possible to operate the previously illustrated boiler settings with a low draft regulated by the damper to the smokestack and at the same time avoid dust or gas explosions inside the furnace or in the shavings pipes and cyclone.

The greatest danger is present in the morning or at other times when the boiler is fired up after having been down for several hours. In such case the boiler is filled with dry shavings or sawdust and the heat from the brickwork raises the temperature of the fuel to a point where wood gas is distilled off faster than the smokestack can carry it away, and it is merely a question of time until this gas ignites and produces an explosion which may wreck the entire boiler setting. Such an explosion took place when the above-mentioned horizontal return tubular boilers were first rebuilt and was caused by the carelessness of the fireman, but this was the only explosion he ever had. To prevent their occurrence, it is only necessary to light the fire and let the gases burn as they are given off from the fuel.

FIG. 5 363-HP. BOILER WHICH IS AN ENLARGEMENT AND IMPROVEMENT OVER THE ONE SHOWN IN FIGS. 3 AND 4

Backfires from the firebox through the shavings pipe and into the cyclone have occurred and have been the cause of serious

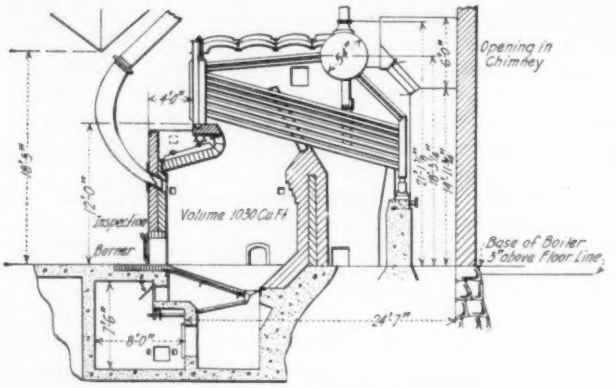



Fig. 6 View of Front of Boiler Shown in Fig. 5

accidents. To eliminate this danger, a cast-iron chute is placed in the front wall of the boiler and fitted with a cast-iron balanced check damper which, as long as pressure is carried in the cyclone, remains partly open and passes the stream of shavings while it retains the greater part of the air. Should the pressure in the firebox exceed that in the shavings chute or should the blower or fan which feeds the cyclone cease to function, this check valve will automatically close.

Serious accidents have taken place caused by either of the above causes, and it is well worth while to take the proper precautions and properly instruct the operating force to eliminate any chance of their occurring.

The proper utilization of wood as fuel has been neglected for many years, but because of the increased price of coal and the competition between manufacturers in the same line, the matter of proper utilization of wood refuse for fuel has of late been given very great consideration.

There are now scattered all over the country factories where wood burning has reached the highest degree of efficiency, and it is to be hoped that every plant that has any considerable amount of wood or refuse which can be burned, will see fit to adopt means and methods for utilizing such fuel to the best advantage.

# Wood-Burning Furnaces WDI-50-16B

By BURRITT A. PARKS,[1] GRAND RAPIDS, MICH.

*After pointing out the value of wood refuse as fuel for boilers in woodworking plants, the author discusses the nature of wood refuse and the heating value of various species of wood. He then considers the conditions which are necessary for the efficient combustion of wood refuse, and sets forth the principal requirements in the case of kiln-dried wood, after which he describes various furnace designs which have been successfully employed. He closes with an appeal for better engineering in the design and operation of woodworking plants.*

MUCH has been written of late regarding the proper design of wood-refuse-burning furnaces and the efficient combustion of wood refuse as a fuel. While the author does not presume to add greatly to the sum total of knowledge on these subjects, he nevertheless believes that a résumé of recent developments, together with the results of some of the experiences of his company, may not come amiss in furthering the discussion of these important problems.

The increased cost of coal during and following the World War, together with the propaganda carried on by various Government agencies and engineering societies in the interest of conservation of fuel, have combined to open the eyes of power-plant owners and operators to the possibility of reducing fuel consumption and therefore cutting operating costs. Much has been accomplished along this line, but judging from appearances in many manufacturing plants, there is still much work to do.

The managements of many woodworking plants have in the past apparently labored under the misapprehension that the wood refuse resulting from their manufacturing operations was a waste product pure and simple and that its disposal was the primary consideration, economy in its use being of little or no importance.

Intelligent thought will convince one that this is the wrong point of view, particularly for a plant where the wood refuse is insufficient to supply the demand for fuel, for, as will be pointed out later, every 2 to $2^1/_4$ lb. of wood efficiently burned in the furnace results in the saving of 1 lb. of coal, and this gives a real dollars-and-cents value to the refuse viewpoint.

In order to accomplish the maximum in fuel savings, certain conditions must be met, such as proper furnace design, suitable means for feeding the wood refuse to the furnace, and intelligent operation. Incomplete combustion and excessive temperature of the stack gases are the two most potent causes of the inefficient use of fuel. The proper control of these factors is not a matter of guesswork; neither is it entirely a question of experienced observation. Data must be supplied to the fireman so that he may definitely control the drafts, air supply, and fuel supply in accordance with the load conditions. To this end certain instruments are necessary, such as steam-flow meters, draft gages, recording thermometers, and flue-gas analyzers. There are many who will question the advisability of making the investment in such instruments. The author's only answer to this is that the increased efficiency resulting from positive control of combustion conditions will pay a surprising return on the investment—and this statement is not based on idle generalities but is the result of observation and experience in plants under his charge.

### Value of Wood Refuse

The amount of wood refuse available as fuel in a woodworking plant will, of course, vary with the nature of the product. In most furniture-manufacturing plants, for example, the waste will vary from 25 to 40 per cent of the lumber cut; 30 per cent would probably be a conservative average. This means that for every 1000 ft. b.m. of lumber cut, averaging about 3 lb. per ft. b.m., there will be 1000 lb. of refuse sent to the boiler room, which, when efficiently used, will replace 500 lb. of coal.

Very frequently manufacturers will sell their cuttings for domestic uses, and they should not lose sight of the fact that every load of cuttings sold, in most cases at least, must be replaced by the equivalent fuel value in coal. This means that the manufacturer should dispose of the cuttings at a price that will at least allow him to buy an equivalent fuel value in coal for the

[1] Consulting Engineer, Byron E. Parks & Son. Mem. A.S.M.E.

Presented at the National Meeting of the A.S.M.E. Wood Industries Division, Grand Rapids, Mich., Nov. 26 and 27, 1928.

same money. A survey was recently made at a woodworking plant where the cuttings had been sold for years at a price that would not purchase a fuel equivalent in coal. Manifestly this was a poor bargain for the manufacturer.

Due to the fact that most woodworking plants require steam throughout the year for lumber drying and other process work, it is necessary to operate a boiler plant throughout the year, irrespective of whether power is developed or not. Taken in conjunction with the fact that large quantities of wood refuse are available for fuel and that exhaust steam from engines is exactly as satisfactory a heating medium as low-pressure steam from the boilers, it may easily be shown that in over 90 per cent of the cases, woodworking plants cannot afford to purchase outside power at rates ordinarily in effect. The wood refuse available as fuel is the predominant factor affecting this situation, and it therefore behooves any woodworking plant purchasing power to make a careful survey of its steam and power demand, for in most cases there is an opportunity for effecting substantial reduction in the cost of these items.

### Nature of Wood Refuse

Before discussing the proper conditions for the efficient use of wood refuse as fuel and the design of wood-burning furnaces, it is essential to have an understanding of the nature of the fuel it is proposed to burn. The lumber industry has practically disappeared from this section of the country, and consequently this discussion will be confined to a consideration of the wood refuse ordinarily available in woodworking plants of this and similar communities. For the purpose of this paper only kiln-dried or thoroughly air-dried stock will be considered.

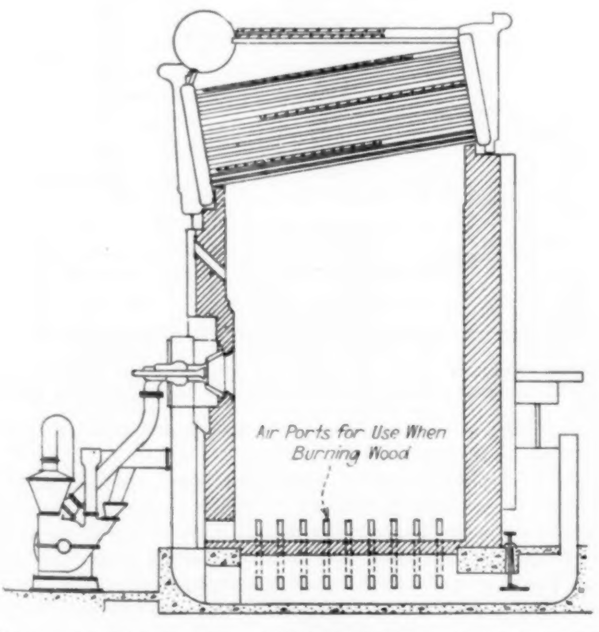



Fig. 1 Cross-Drum Type of Water-Tube Boiler With Boxlike Furnace for Burning Wood Refuse

It is generally assumed that the heating value per pound of dry wood is the same for all species, as the composition of dry wood is approximately as follows: carbon 49 per cent, oxygen 44 per cent, hydrogen 6 per cent, and ash 1 per cent. As a matter of fact, the different species contain varying amounts of resins, oils, and gums, so that the actual composition and heating value, as given by Gottlieb, is as follows:

| Kind of wood | C | H | N | O | Ash | B.t.u. per lb. |
|---|---|---|---|---|---|---|
| Oak | 50.16 | 6.02 | 0.09 | 43.36 | 0.37 | 8316 |
| Ash | 49.18 | 6.27 | 0.07 | 43.91 | 0.57 | 8480 |
| Elm | 48.99 | 6.20 | 0.06 | 44.25 | 0.50 | 8510 |
| Beech | 49.06 | 6.11 | 0.09 | 44.17 | 0.57 | 8591 |
| Birch | 48.88 | 6.06 | 0.10 | 44.67 | 0.29 | 8586 |
| Fir | 50.36 | 5.92 | 0.05 | 43.39 | 0.28 | 9063 |
| Pine | 50.31 | 6.20 | 0.04 | 43.08 | 0.37 | 9153 |

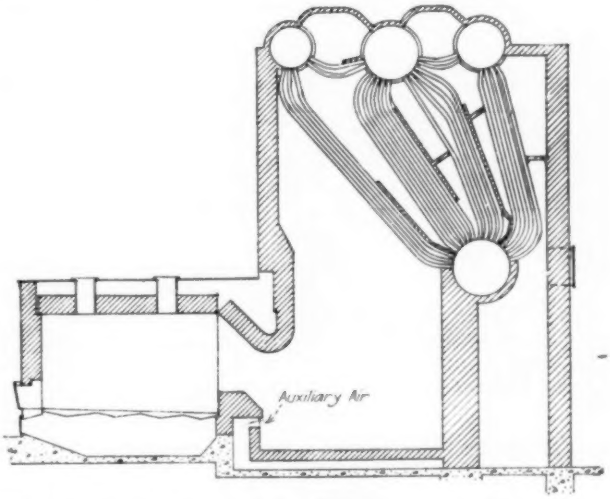



Fig. 2 Type of Furnace Found Successful in the Burning of Wet Hog Fuel

To show the variation in heating value of wood due to water content the following table, given by J. H. Hinman, is presented.

| Moisture, per cent | Available heat, B.t.u. per lb. |
|---|---|
| 10 | 7703 |
| 20 | 6705 |
| 30 | 5707 |
| 40 | 4710 |
| 50 | 3712 |
| 60 | 2715 |
| 70 | 1717 |

This table is based on a heating value of 8700 B.t.u. per pound of wood with an assumed flue-gas temperature of 560 deg. fahr. The available B.t.u. per pound of wood fuel indicates the net heating value after deducting the B.t.u. required to heat the moisture to the boiling point, evaporate it, and superheat it to the temperature of the flue-gas temperature, viz., 560 deg.

From an examination of the above tables it will be observed that the B.t.u. value of the common species of woods carrying about 5 per cent of moisture will be about 50 per cent of that of a good grade of bituminous coal. In other words, for comparative purposes it is conservative to assume that in most woodworking plants two pounds of wood refuse is equivalent in fuel value to one pound of bituminous coal.

In burning wood the volume of gases given off is much larger than for coal, and, as will be shown hereinafter, this fact has an important bearing on the design of boiler settings, breechings, chimneys, etc. The following table, as given by R. L. Beers,

| Moisture per cent | Efficiency, per cent | Wood per hp-hr. as fired, lb. | Flue gases per hp-hr., lb. | Cu. ft. per hp-hr., at 600 deg. | Ratio of gas volume, wood to coal |
|---|---|---|---|---|---|
| 0 | 70 | 6.00 | 61 | 1560 | 1.11 |
| 20 | 65 | 8.05 | 66 | 1715 | 1.22 |
| 40 | 57 | 12.25 | 80 | 2120 | 1.51 |
| 60 | 43 | 24.40 | 114 | 3150 | 2.24 |

indicates the approximate volume of flue gases, assuming a temperature of 600 deg. fahr.

### Conditions for Efficient Combustion of Wood Refuse

As has been pointed out above, the combustion of wood refuse results in the giving off of a large volume of gas. It therefore

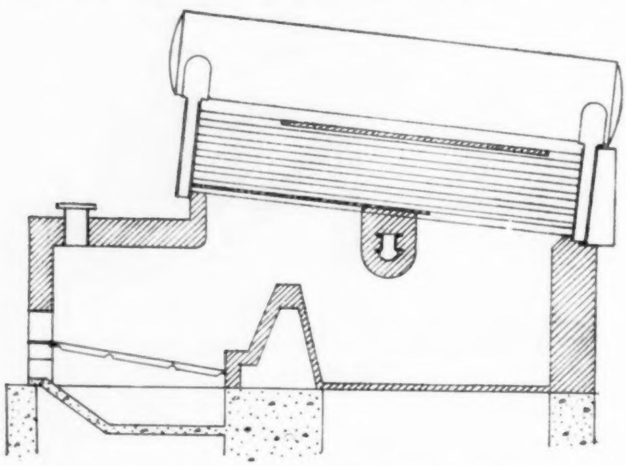


Fig. 3 Special Furnace Designed for Burning Both Wet and Dry Wood Refuse

requires a design of furnace different from that required for coal to obtain the best results.

The practice ordinarily in vogue for supplying fine refuse to the furnace is to either spout it directly from the separator or else use some special design of feeding mechanism conveying the refuse from a storage bin. In any event, a considerable portion of the sawdust and shavings is burned in suspension and the remainder drops in piles on the grate, when combustion takes place largely on the surface of the piles. Due to the impossibility of obtaining an adequate air supply through the fuel bed itself, air must be admitted above the fire. If there is a deficiency of air admitted above the grate, incomplete combustion will result, and in consequence heavy black smoke will be given off.

In general, the fuel bed should not be disturbed as combustion, which is taking place on the surface, will be interfered with.

One of the largest sources of loss in most plants results from the fact that fuel and air are not properly proportioned and supplied to the furnace in accordance with the load on the boiler. For this reason, automatic means for feeding the fuel to the furnace, as will be described hereinafter, should be employed in order that the highest efficiency in the use of the fuel will result. It has been conclusively demonstrated that the savings resulting from proper means of regulating the fuel supply will pay handsome returns on the investment required to accomplish this object.

Kiln-dried wood, sawdust, and shavings are burned to a great extent in suspension, and on account of the large volume of gas given off and the necessity of obtaining a thorough intermingling of the air with these gases a large combustion space is necessary. There is a tendency toward larger combustion spaces, and whereas 3 to 5 cu. ft. of space per rated horsepower was considered ample a few years past the author believes that 7 to 8 cu. ft.—or even more—per horsepower of rated boiler capacity will give better results.

In large boiler plants having a number of boilers installed, part of the settings may be designed to burn wood only and the remainder designed for coal. In most plants, however, the settings should be designed for a combination of coal and wood refuse so that no interference with operation will result from a stoppage of the wood supply. The method of coal firing to use depends somewhat on the size of the boiler unit and the ratio between the coal and wood refuse required to carry the load. Stokers and pulverized coal are coming into use rapidly, and have the advantage that automatic control will "cut in" the coal supply as the supply of wood refuse drops off.

In many ways unit pulverizers form the ideal scheme for feeding coal as they are more responsive than the stoker in taking care of variations in the wood supply.

Another advantage in using pulverized coal is that grates may be omitted entirely. As has been mentioned, refuse such as kiln-dried shavings and sawdust burns best on the surface of the piles, and consequently a plain brick bottom to the furnace answers every requirement. Air is admitted through small openings near the furnace bottom directed toward the piles. With this design hollow-wall furnace construction is advisable as

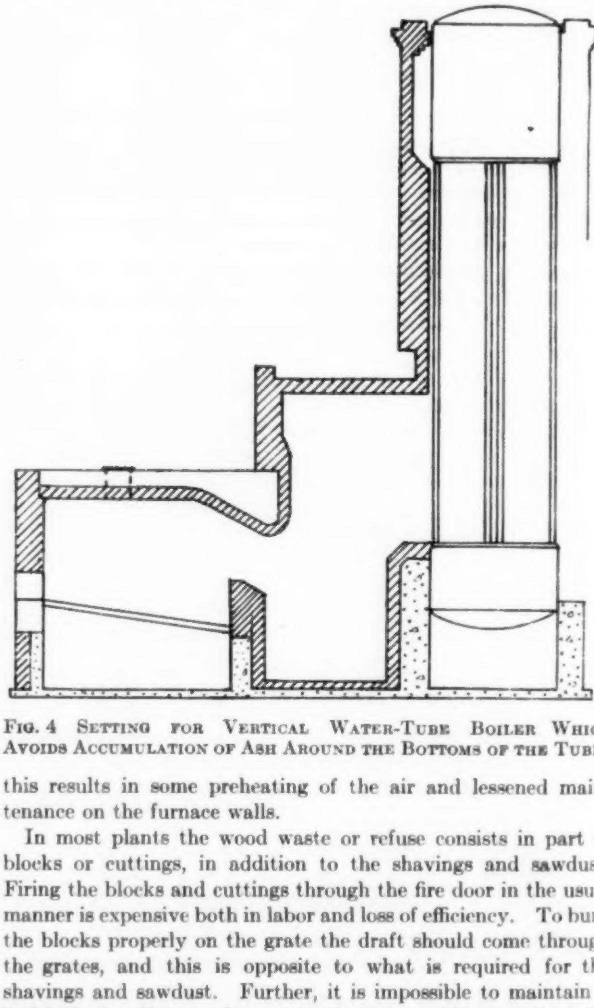


Fig. 4 Setting for Vertical Water-Tube Boiler Which Avoids Accumulation of Ash Around the Bottoms of the Tubes

this results in some preheating of the air and lessened maintenance on the furnace walls.

In most plants the wood waste or refuse consists in part of blocks or cuttings, in addition to the shavings and sawdust. Firing the blocks and cuttings through the fire door in the usual manner is expensive both in labor and loss of efficiency. To burn the blocks properly on the grate the draft should come through the grates, and this is opposite to what is required for the shavings and sawdust. Further, it is impossible to maintain a fuel bed of uniform resistance, and consequently control of the air supply is impossible.

There is only one answer to this condition, and that is to "hog" the blocks and cuttings. The "hogs" may be located at strategic points throughout the plant (resulting in a decrease in labor for trucking), and the hogged material delivered into the regular exhaust system.

In spite of the comparatively large power consumption and maintenance required for the "hog," tests have shown con-

clusively that in most cases the decrease in labor and increased efficiency in burning the hogged material will show savings that will pay a good return on the investment.

## Descriptions of Various Furnaces

The principal requirements for the efficient combustion of kiln-dried wood refuse may be summed up as follows:

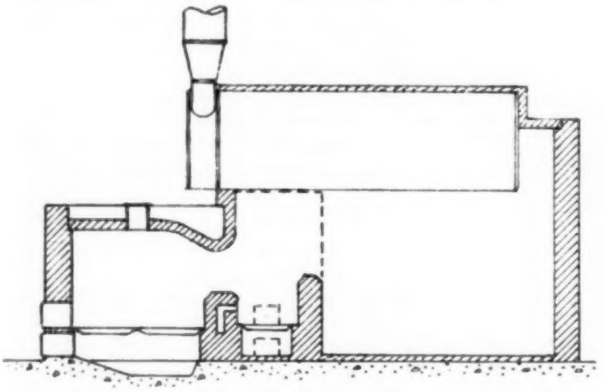


Fig. 5 Successful Type of Setting for Horizontal-Return Tubular Boiler

1 Ample combustion space to insure as complete combustion as possible before the hot gases come in contact with the water-heating surface
2 Means of feeding the wood refuse whereby the supply of refuse may be controlled in accordance with the load
3 Means for admitting the air supply to the furnace at the proper points and controlling it in synchronism with the fuel supply
4 Ample draft, but with means for controlling it, preferably automatically, so that the fine particles will not be unduly drawn over the bridge wall or into the gas passages of the boiler
5 Suitable means of firing coal as an auxiliary fuel, preferably using stokers or a powdered-coal installation, arranged with automatic control so that the auxiliary fuel will "cut in" as the supply of wood refuse drops off. Parenthetically it might be stated that oil fuel and natural gas make ideal auxiliary fuels, but on account of the cost or not being available, they are seldom used
6 Proper complement of instruments, such as steam-flow meter, $CO_2$ indicator, draft gages, thermometers, etc., so that the fireman may intelligently control the various elements of the installation to give the maximum possible efficiency at all times.

Keeping in mind these requirements, it may be of interest to examine a few typical furnace designs and see how these requirements are met.

Fig. 1 indicates a cross-drum type of water-tube boiler set over a large box-like furnace. A unit-type coal pulverizer is used to supply the auxiliary fuel. No grates are used, the bottom of the furnace being of brick. Wood refuse is spouted from a screw feeder (not shown) through the diagonal chute in the front wall. Air is admitted through the openings shown near the bottom of the furnace. Some experiments have been conducted with furnaces of this type using steam jets in some of the air inlets in order to obtain an agitation of the wood refuse dropping to the floor of the furnace. Results seem to indicate a slight improvement over natural draft. This boiler has been run at 200 per cent of rating continuously on wood refuse alone.

While we have been considering dry refuse only in this paper, Fig. 2 is given to indicate a successful furnace for wet hog fuel, such as would be available in a lumber mill. The fuel is introduced through the two openings in the top of the Dutch oven. The drop-nose arch aids materially in the combustion of this type of refuse by increasing the area of hot brickwork reflecting heat to the fuel bed, preventing stratification of the air and gases, and producing a high furnace temperature so essential for the proper combustion of wet refuse. Additional air is introduced through a hollow bridge wall to insure sufficient oxygen for burning the gases distilled from the fuel bed.

Fig. 3 shows what may be accomplished in the way of a special design to meet various limitations. The furnace was designed to burn both wet and dry refuse. On account of space limitations both as to length and height, the furnace volume is not all that might be desired. To overcome the deficiency in hot brickwork in the furnace, horizontal baffling was used. This not only increased the area of brickwork reflecting heat to the fuel bed, but also increased the length of gas travel. The suspended drop-nose arch accomplishes the same purpose as in Fig. 1. This furnace has met the requirements of smokelessness very satisfactorily. Ordinarily vertical baffling is preferred by the author in order to

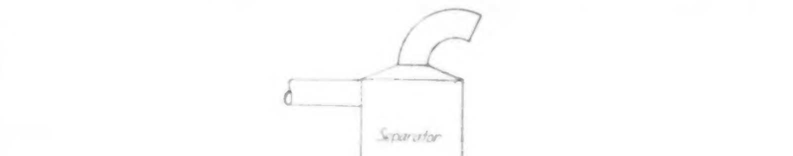



Fig. 6 Showing Means of Obtaining Uniform Feeding of Refuse

obtain a flow of the gases across the tubes and to prevent accumulations of ash on the horizontal surfaces, but in this case these advantages were offset by the desirability of obtaining the greater heat-reflecting surface and larger combustion space before the gases come in contact with the heating surface.

Fig. 4 shows a furnace somewhat similar to that in Fig. 1. The practice in the past has been to bring the furnace proper right up against the tube bank in vertical water-tube boilers. This resulted in the products of combustion coming in contact with the heating surface before combustion was sufficiently advanced. A large accumulation of ash around the bottom of the tubes and a dirty stack was the result. The setting shown in Fig. 4 very successfully overcomes the above disadvantages.

Fig. 5 shows a very successful setting for a horizontal-return tubular boiler. The auxiliary grate catches and burns a large amount of the fine shavings and sawdust that blow over the bridge wall. Air may be admitted below this grate and also through the hollow bridge wall above the grate.

Fig. 6 is given not so much to show a successful furnace as to indicate a means of obtaining uniform feeding of the refuse. In this case the refuse is the auxiliary fuel, coal being depended upon primarily. It will be noted that space limitations prevented designing a furnace of adequate proportions for successfully burning wood refuse.

The shavings, sawdust, and dry hogged cuttings are delivered from the separator to an overhead steel bin. From the bin the refuse flows by gravity to a screw conveyor, which in turn discharges through the top of furnace near the front. The speed of the conveyor, and consequently the rate of fuel feed, is under control of the fireman by means of a friction drive from a line shaft. Agitators are provided in the bin to prevent the material from "bridging." An air blast from a small fan is introduced into the discharge chute, as indicated, to prevent flarebacks and to obtain a better distribution of the refuse in the furnace. A runway passes over the tops of the furnaces, so a large chute and trap door are provided in each furnace for feeding rubbish and such wood refuse as cannot be put through the hog.

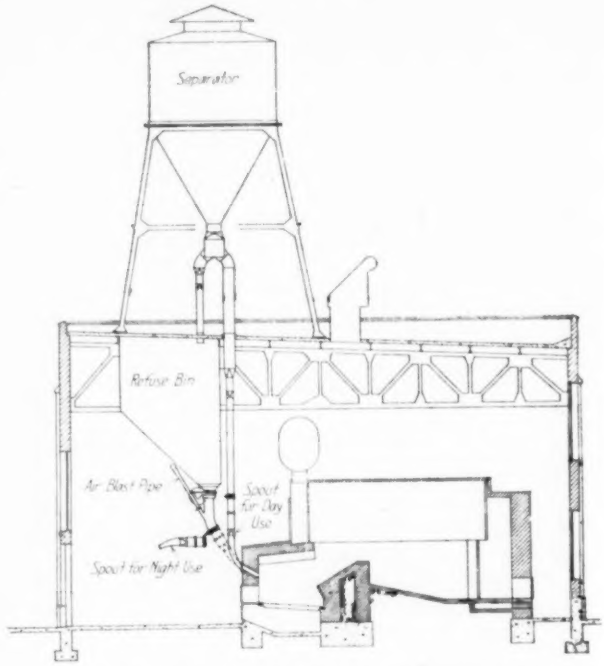



Fig. 8 Design of Moderate Cost for Small Plant

Fig. 7 shows a design which has worked out very successfully, both from the standpoint of the furnace and the method of feeding the coal and refuse. As will be noted, the furnace design is similar to that in Figs. 2, 4, and 5, using the drop-nose arch and auxiliary air inlet through the bridge wall.

The refuse is discharged from the separator into a large brick storage bin in the bottom of which is a double screw conveyor, the two screws turning in opposite directions and inwardly at the top. The screw conveyor conveys the refuse to a small exhaust fan, which in turn discharges to the secondary separator on the roof. From the sec-

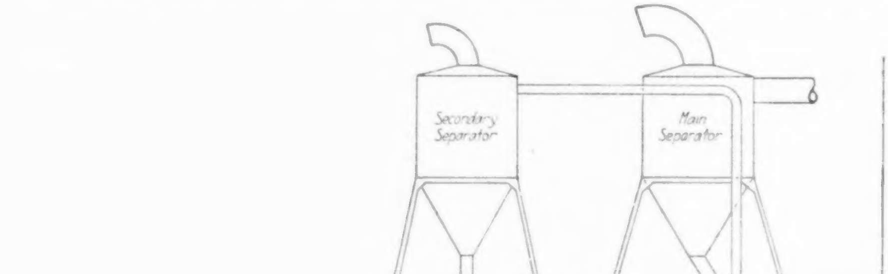



Fig. 7 Successful Design Both as Regards Furnace and Method of Feeding Coal and Refuse

ondary separator the refuse flows by gravity to the furnace in the usual manner. By means of a variable-speed motor the speed of the screw conveyor, and consequently the rate of flow of refuse to the furnace, is controlled in accordance with the load on the boiler.

As an auxiliary to the above a unit-type coal pulverizer and feeder is installed which is provided with automatic control so adjusted that if the supply of wood refuse is insufficient to carry the load the coal feeder will cut in automatically.

Fig. 8 indicates a furnace design and method of feeding used in a small plant where the expense of more elaborate equipment did not seem justified. In this case the shavings and sawdust are spouted direct to the furnace from the separator in the usual manner, the excess going to an overhead steel bin. Practically all cuttings are run through a hog and discharged to the same bin. When the manufacturing plant is not in operation the spout from the bin is inserted in the chute to the furnace and the contents of the bin discharged to the furnace by gravity, aided by the siphonic action of a jet of air from a fan. An agitator is installed in the bin to prevent bridging and to insure a fairly uniform rate of discharge.

This design is not offered as an ideal one, but it shows what may be accomplished at moderate expense. The refuse from this bin is fed to the furnace and consumed with far greater efficiency than would be obtained by feeding the material through the fire doors with a shovel.

The extended lip on the bridge wall induces a swirling action in the furnace which prevents stratification and insures a more intimate mingling of the air and gases. In this particular case this projecting lip had to be reduced somewhat from that shown, as it was found that too high a furnace temperature was obtained, resulting in high maintenance of the furnace walls and arch.

In conclusion, the author wishes to make an appeal for better engineering in the design and operation of woodworking plants. The woodworking industry has dropped far behind many other industries in the progress shown in plant design, manufacturing methods, etc. With the increasing keenness of competition it behooves every plant executive to scrutinize all departments of his plant with the greatest care. Today the saving of pennies in reducing costs may be as important as the saving of dollars was yesterday.

## Discussion[2]

Sern Madsen.[3] The paper is very complete in covering the subject of wood-refuse burning as conducted in the majority of woodworking plants, but it does not cover at all the apparatus or conditions of wood-refuse burning found in the larger and more efficient installations for burning of dry wood refuse.

The methods and apparatus described are those used in the average small mill burning dry wood refuse. Further than this, the installations described are designed and arranged for use of other fuel as make-up when wood refuse runs short.

Briefly, it describes the methods adaptable either to the small plant or to the larger plant where wood-refuse burning is a minor consideration.

The most efficient installation where wood refuse constitutes the major part of the fuel, or all of it, must be developed along radically different lines.

Reasons why the comparatively flat grates and "blow-in" system of feed are inefficient are:

1 The ratio of air to fuel entering above the grates varies as machines producing shavings vary.

2 The rate of fuel feed is not easily controlled to meet the demands for steam production.

3 The fuel burns like a bonfire, with cold air for maintaining combustion approaching the fuel from the top—the same side from which the heated gases resulting from combustion must leave. The highest temperatures cannot be obtained where the hot gases are extensively diluted with an excess of cold air.

4 The burning of the fuel is uneven. The air supply is not uniform to all parts of the fuel.

5 Building up of a cone or heap of shavings is ideal for generating gases for a subsequent explosion.

Other considerations that are essential for efficient wood-refuse burning are as follows:

1 The rate of fuel feed must be proportional to the demands for steam production and should preferably be automatically controlled.

2 The ratio of air for combustion and fuel feed should remain practically constant.

3 The fuel bed should entirely cover the grates and should be of nearly uniform depth. No holes in the fire should be permitted.

4 The air for combustion should enter primarily from below the grates so that the hot gases of combustion can leave uncooled from the top side of the fire.

5 Except in extremely high furnaces the theory of burning wood refuse in suspension is a myth. Therefore we must have grates.

To obtain the above conditions as nearly as possible, and to gain other advantages,

1 The air and fuel supply may be controlled by the steam pressure and maintained at a predetermined ratio.

2 Proper distribution of fuel on the grates can best be obtained by use of several gravity-feed chutes at or near the high end of a grate which slopes at from 30 to 40 deg. from the horizontal toward the back.

3 By keeping a well-distributed fuel bed of uniform depth, a moderate draft will supply a uniform air supply to all parts of the fuel.

4 A mechanical feed of shavings makes possible a storage of fuel when there is a surplus which may later be burned during a shortage.

5 All blocks and strips should be ground up in a hog and fired through the chutes like shavings.

6 Safety from backfiring or explosion is positively assured and does not depend on educating the fireman.

7 Smoke conditions are more easily controlled, but it should be remembered that burning of pitchy or knotty wood is not done most efficiently without some smoke.

8 Boiler-room labor and worry will be reduced by automatic apparatus.

As evidence that automatic gravity-feed wood-refuse burning is the most efficient, it might be stated that the largest of the sash and door plants along the Mississippi River have changed from the type of apparatus the author describes to the more modern types of feeding apparatus.

It might also be added that a change-over from the old apparatus at a Clinton, Iowa, plant saved during the first year's operation 2700 tons of coal on a 600-boiler-hp. installation.

In conclusion, let us decide first whether our furnace is to be designed for burning wood refuse as a major fuel or as a means of disposing of it along with other fuel. If the latter, then the author has described suitable apparatus, which, however, might be more efficient.

I. B. Whinery.[4] We had an experience with a small hori-

[2] Joint discussion of E. Winholt's paper on "Obtaining the Maximum Fuel Value From Wood Waste," and the preceding paper by Mr. Parks.

[3] Curtis Companies, Inc., Clinton, Iowa. Mem. A.S.M.E.

[4] Manager, Waddell Mfg. Co., Grand Rapids, Mich. Assoc-Mem. A.S.M.E.

zontal-return tubular boiler of about the size mentioned in Mr. Winholt's paper. We wanted to work out an economical way of keeping out this excess air, and devised a method which we think has possibilities. We located a slide in the down spout and operated it by a small motor-driven unit so that the slide would close off the opening for 50 seconds out of a minute and then open it up for 10 seconds. This allowed a charge of shavings to accumulate above the slide, which would drop into the furnace together with a gust of air, when the slide would close for another accumulation period. The idea was ultimately to provide it with a variable-speed mechanism so that when the shavings were coming faster the apparatus could be worked with a smaller accumulation period. One trouble was that the dust arched over in the spout from the slide, but it is believed that that can be overcome. We found that the device cut our coal consumption from 1000 lb. per day down to about 700 lb. per day, which shows it is possible to make a saving by keeping out excess air.

C. A. Crytser.[5] In designing the damper, Mr. Winholt had the control of air in mind as well as the safety feature. With this damper sufficiently weighted, it limits the amount of air to just about that necessary to carry the shavings into the furnace. For that reason he must supply his air at some other point. The air is supplied very largely through the damper, but the amount is controlled by hand and not automatically. Some sort of regulator might be devised, but it would have to operate on $CO_2$ content in order to take care of the situation. Mr. Winholt has found it possible to control the amount of air through hand operation, and obtain reasonable economy.

Mr. Parks showed on the screen two furnaces where there were large areas of floor. With powdered-fuel furnaces in Chicago, using tile on the floor has not been entirely satisfactory due to slagging which practically prevents heat transfer to the air.

Cast-iron plates, however, have been found to work perfectly. It is possible to blow the scale off them, and even with the high temperatures encountered in burning pulverized fuel there was never any trouble with burning of the plates.

As to squeezing moisture from the wet fuel in sugar mills with four to six hundred tons pressure on the rolls, it is impossible to get the moisture of the bagasse under 40 to 50 per cent.

R. K. Merrill.[6] We are operating 1700 b.hp. with four units, three of which are required during the factory operating period. All boilers are provided with screw feeds for shavings, which enter the boiler furnace through the furnace roof close to the furnace front. Two of the boilers are stoker-fired, using type E single-retort stokers made by the Combustion Engineering Company. The other two boilers are provided with plain herringbone grates, and the larger portion of the shavings is consumed in these two furnaces.

Originally, these last-mentioned furnaces were somewhat larger, but we found it necessary to install an air-cooled center wall between these two units which cut down the combustion space somewhat. The present furnaces are large enough to give us 1.66 cu. ft. of combustion space per b.hp. ahead of the first tube bank. We find that the air-cooled center wall saves considerable maintenance expense on the setting. Previous to the introduction of this center wall, we were considering an increase in the combustion space by dropping the grates down into the ashpit, which is rather deep, due to the fact that the boiler room has a basement underneath and ashes are removed at this point. We therefore agree with Mr. Parks that a maximum possible combustion space similar to installations for powdered-coal burning would be desirable.

The Ford Motor Company installed at the Lincoln plant a pair of return tubular boilers, which were originally obtained from some of the ships scrapped by the company, over a furnace which was in excess of 24 ft. high above the grates. This was for wood-refuse burning, and the writer is informed that the setting is very satisfactory. There is, of course, a limit to the size of wood-burning furnaces which is determined by the cost of these furnaces and beyond which point it would not be economical to go.

We find that the automatic control referred to by Mr. Parks is very handy for controlling the speed of the stoker engine which drives the shavings screws. It was a very simple matter to connect a wire from the valve on the engine to the hydraulic damper and turbine-control mechanism furnished with the type E stokers. This gives us a very close control of our steam pressure, which is not usual in wood-burning plants depending upon manual control of the draft and fuel.

We are using a crusher of the swinging-hammer type for reducing our blocks and cuttings to a size suitable for handling in the blow-pipe system. This has no knives requiring frequent sharpening, but the power consumption is rather high. We have found that a periodical tearing down and inspection of this machine every six weeks has paid well over a period of three years. Originally, the machine was set up and run until something happened, but the recurring frequency of these accidents, together with several fires, taught us the necessity for the above-mentioned practice. No material with nails or pieces of metal in it is fed through the machine. Incidentally, this machine now requires a motor which is twice the size of the one recommended by the maker.

C. A. Hamilton.[7] When I came to Grand Rapids and came in contact with the woodworking factories, I found that a $CO_2$ content of 4 to 6 per cent was a high average for the ordinary run of plant where they shoot shavings through the cyclones. In one plant with three boilers equipped with Dutch ovens, we installed screw feeders from a storage bin on each boiler, operated by a motor through a flexible drive with a 10 to 1 ratio. The flue-gas analysis on that installation was so low that I am ashamed of it. On the other hand, the performance seemed fairly good. The coal consumption went down, and in general the operation has been very satisfactory.

A screw feeder installed on a cyclone may produce a nuisance through the dust that carries over from the top. The city of Grand Rapids got after our company for such a nuisance, so we started out to eliminate that dust, which we did by piping from the cyclone into a bin where we sprayed the dust, and then enlarged the pipe area to a point where we reduced the velocity of the air down to about 3 ft. per sec.

R. K. Merrill.[6] Referring to Mr. Hamilton's remarks: With a portable $CO_2$ apparatus we have shown at least 13 per cent of $CO_2$ in our furnaces with plain grates, where the majority of our shavings are burned. Some hand-fired coal was also burned at the time of these tests.

C. A. Ross.[8] In the second table of Mr. Parks's paper it is stated that the available heat per pound of fuel with 70 per cent moisture is 17.7 B.t.u. That means a pound of fuel is 0.59 lb.

[5] Tower Construction Co., Chicago, Ill. Assoc-Mem. A.S.M.E.

[6] Industrial Mechanical Engineer, American Seating Co., Grand Rapids, Mich. Mem. A.S.M.E.

[7] Giffels, Hamilton & Wecher, Grand Rapids, Mich. Mem. A.S.M.E.

[8] Vice-President and Engineer, Piqua Handle & Mfg. Co., Piqua, Ohio. Assoc. A.S.M.E.

dry wood and 0.41 lb. of water. The removal of that water from the wood would take approximately 1000 B.t.u. per lb., or 420 B.t.u. for 0.41 lb. By removing it the fuel could be charged into one having 7000 B.t.u. per lb. The question arises whether any one has ever tried to dry wood refuse with heat from the stack before burning it, thus getting the additional heat indicated.

Kent says the heating value in B.t.u. per lb. dry is from 5400 to 6830. The heat at 70 per cent wet would be:

$$\left(\frac{100}{170}\times 6000\right)-\left[(212-50)\times 1+970+(600-212)\times 0.5\right]\frac{70}{170}$$
$= 2950$ B.t.u. (about)

Here

6000 = average B.t.u. per lb. of dry fuel above 50 deg. to 600 deg. fahr.
50 = initial temperature of fuel
970 = latent heat of contained water
0.5 = specific heat of steam
600 = final temperature of flue gases.

Theoretically there is only a saving of 194 B.t.u. by previous drying, and this will be lost in the drying, but the previous drying will bring about a higher furnace temperature.

B. M. Baxter.[9] I wish to emphasize the excellent point brought up by Mr. Parks, that the volume of furnace gases needs very careful consideration, especially where there is moisture in the fuel.

Some ten or twelve years ago I had occasion to look into the performance of certain boilers which were being fired with a material similar to spent bark in a tanning-extract plant in the South. This material ran very wet. The plant had been designed with vertical boilers much like those shown in this paper, except the tubes were small and the spaces were quite close. Fortunately, there was induced draft available, but one thing which was extremely puzzling was an excessive draft drop through those boilers.

A little thought in connection with the large amount of moisture contained in that fuel, which ran around 65 per cent, indicated that the volume of gases was far beyond the normal amount. That explained the high draft drop, which was corrected by a change in the baffling.

An interesting point in connection with the use of high-moisture-content fuels was the recovery of the heat from the stack gases. Naturally, with a large amount of moisture which must be evaporated and superheated, the stack losses are excessively high. In this instance, special economizers were designed.

Experience in another plant in that neighborhood indicated that the ordinary cast-iron tubes could not be used in the economizer because a deposit would stick to them and clog the scrapers. In fact, so much trouble developed with the cast-iron economizers that they were abandoned. In this case an economizer was developed using a steel-plate tank, through which ordinary boiler flues were thrust, expanded, and rolled in. This economizer proved quite successful and about 150 deg. rise was obtained in the feedwater. However, on account of the slow circulation of water in this economizer the tubes corroded and pitted quite rapidly.

It is quite common practice to discharge shavings from cyclones direct into the furnace. Considerable air is required to transport the shavings. The question arises how to adjust the amount of air necessary for the mechanical transport of the shavings to the amount properly needed for combustion.

Paul H. Bilhuber.[10] We have found it very satisfactory to combine coal and shavings in the same furnace and then discontinue the use of coal, reserving this furnace entirely for wood shavings, and have secured fairly good efficiency from it on that basis. I should like to ask whether Mr. Parks's furnace design is applicable to both shavings and pulverized coal, and whether an immediate change can be made from shavings to pulverized coal and the same efficiency be had from either of those fuels. Also whether it is possible to economically pulverize No. 1 buckwheat anthracite and whether that is less efficient to pulverize than bituminous coal or anthracite of the larger sizes.

B. M. Baxter.[9] The difficulty about spouting direct from the cyclone arises from the fact that the stock comes into the cyclone intermittently as it is freed through the machines in the plant. The blast in the cyclone is nearly constant at times, the fuel will come down in great volume, and again the spout will be empty. In considering this matter in the rearrangement of a plant ten or twelve years ago, the expedient mentioned by Mr. Parks, that is, a screw feeder, was adopted, which eliminated the difficulty. In my opinion it is the only proper way to feed.

C. W. Gordon.[11] I should like to ask a few questions. First, what commercial disposal is made of the wood ash? Second, what $CO_2$ is maintained in these furnaces? Third, what flue gas temperatures are obtained? Fourth, what boiler efficiencies are obtained with the various arrangements which have been shown on the screen? One type of furnace which has not been discussed consists of an airtight pressure chamber into which wet wood chips are fed by conveyor. Air at forced draft is introduced under the grates and a form of wood gas is therefore generated in this chamber. The gases pass through a small throat at high velocity and burn in a large combustion chamber under the boiler. These wood chips therefore burn with a $CO_2$ of from 13 to 15 per cent, and consequently the equipment operates with excellent results. We are interested in the problem mainly from the standpoint of superheater designs. The size of a superheater depends primarily on the amount of gases which pass over it. The $CO_2$ is a measure of the gas weight. Unless we are advised to the contrary it is our customary practice to assume a $CO_2$ of 8 per cent and this discussion indicates how far one can go wrong in a case of this kind.

W. T. Ritter.[12] I wish to second as well as emphasize Mr. Parks's remarks concerning the need of instruments in the average boiler plant, especially that of the woodworking establishment.

In my going from one plant to another, I find more unused $CO_2$ recorders, either automatic or hand operated, and draft gages so dirty that they could not be read if they were hooked up. Therefore it behooves us to think of the human element in the operation and maintenance of these instruments, and the employment of a higher type of operator who will use them more frequently than is now the practice.

I differ somewhat with Mr. Parks on the comparative value of wood and coal fuel. The heating values that he gives are about 2000 to 3000 B.t.u. higher than any authoritative ones I have seen. The average B.t.u. value of bone-dry wood will run somewhere between 7000 and 9900 B.t.u. On the same

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[12] Burke Engineering Co., Holland, Mich. Jun. A.S.M.E.

basis, this figure for wood refuse should be compared with the B.t.u. value of 15,500 for bituminous coal, ash- and moisture-free.

As to the moisture content of the wood as found in most woodworking plants, Mr. Parks states that it is somewhere in the neighborhood of 5 per cent. Our experience in combustion work shows us that it is anywhere from 20 to 30 per cent. Wood refuse, even though it be kiln dried down to 5 per cent, will absorb quickly another 5 or 10 per cent the minute it is released from the bins.

As I see it, however, for every 3 lb. of wood we can expect to save about 1 lb. of coal instead of 2 to $2^1/_4$, as Mr. Parks states. I mention this because some woodworking manufacturers may be disappointed in their savings, and wonder why they are not higher.

There are places for powdered-coal installations in connection with burning of wood refuse and places for stoker installations. Two of the determining factors are:

1 The ratio of the amount of wood available or to be burned as compared with the amount of coal necessary to make up the full-load requirement.

2 The extent and intermittency of the wood supply. That is, how often the wood supply runs out and it is necessary to turn to coal.

Theoretically, powdered fuel would seem to be best for auxiliary or boosting in wood-burning or partial wood-burning furnaces. For the moderate-sized plant, up to 300–350 hp., stoker firing is the more economical when cost of operation, $CO_2$ performance, and efficiency are considered.

We manufacture a small Dutch-oven furnace, which we quite frequently install with so-called Scotch-type boilers, as well as tubular boilers. This furnace has just a little under $^3/_4$ cu. ft. volume per rated hp. Yet when connected up with a Scotch boiler, with about a $13^1/_2$-in. throat between the end of the rear grate and the heating surface of the boiler, we obtain absolutely smokeless results, and under normal operating conditions around rating obtain from 11 to 13 per cent of $CO_2$. The efficiency runs anywhere from 68 to 73 per cent. In a furnace which has a volume of less than $^3/_4$ cu. ft. per hp., these results are largely due to the swirling action caused by the wing walls built as a part of the bridge wall and by the cyclonic effect on gas travel produced by firing alternately opposite sides of the furnace. In the case of the furnace mentioned by the author, I do not believe that the high maintenance cost was due to the swirling action—it was really due to the radiating effect of the heat, which melted or burned away the brickwork.

L. H. Cutten.[13] Much has been said about the savings due to utilizing wood waste as fuel, but little about the cost of getting this wood fuel into the boiler. If the plant is small and the boiler house connected immediately with it, and a single cyclone can be used, it may be simple. The particular problem that we have is a wood shop 1000 ft. from the boiler house, with two or three tons of waste material a day, to be burned under a boiler using from 10 to 30 tons of coal a day. We have not been able to justify the expense to make the saving.

C. B. Norris.[14] What would be the minimum percentage of wood refuse that could be used in conjuction with coal to any advantage? We have possibly but 10 per cent to throw into our furnace. Perhaps there is a point where it would be better for us to burn our wood refuse in a bonfire, rather than disturb the coal in the fire with it.

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### Mr. Winholt's Closure

The discussion on the paper which I presented has brought out a considerable number of theories regarding the burning of wood fuel, and of methods of burning it and of controlling fuel and air. It is conceded that automatic regulation on fuel as well as air is of a great advantage, but the boiler setting, the construction of the furnace, and other details are the most important items in the efficient burning of such fuel.

The paper as presented and the illustrations as shown refer specificially to certain applications. All of these installations are in operation and have been running for a number of years, and experience with these furnaces has indicated their suitability for the purpose. Theories of wood burning may be evolved afterward.

With the methods of furnishing fuel as well as air, which are discussed in the paper, it is absolutely necessary that the fuel be introduced with a certain velocity so that the heavy particles of wood will be delivered on the grate near the bridge wall, at which point they will form a pile which gradually spreads until it covers half or more of the grate. The other part of the grate is to be left uncovered for the admission of sufficient air to efficiently burn this fuel. Combustion takes place around the pile on the grate in the shape of a horseshoe. No air is allowed to come through the pile and burn, neither from the rear nor in the center. The air which enters with the shavings supports the surface combustion, and the fact that $CO_2$ up to and above 15 per cent is easily obtained and no combustible wood is deposited in the rear pass of the boiler is proof that combustion takes place very efficiently.

It is of course contrary to the theories and to the ordinary understanding that wood should be burned in a pile and with surface combustion, instead of being burned on grates with the air passing through them, similar to coal. However, the above method has been tested in the installations described in the paper and is working very satisfactorily.

It is of course necessary to see such an installation to fully grasp its significance. It must be conceded that a 344-hp. boiler with a total furnace volume of 455 cu. ft. and a grate surface of 28 sq. ft., supplied with wood shavings and generating up to 600 to 666 hp., must have some merit to it.

The boilers as described are arranged to dispose also of all factory refuse which is ordinarily swept up around the plant and which must be brought to the boiler room and fired by hand.

In conclusion, it should be stated that a prominent sash and door works located in the Tri-Cities is burning wood shavings exclusively in its power plant and operating an electrical load of approximately 1000 hp. in addition to heating the plant, and that this is being accomplished by burning wood shavings by means of a shavings system and a cyclone feed. The mill wood from this establishment is being sold, and no coal whatsoever is utilized in making steam under the boilers. This concern used approximately 20,000,000 board feet of lumber for its product in one calendar year, and the power plant produced all the heat, light, and power for it, or a total of slightly more than 2,000,000 kw-hr. It is doubtful whether this performance is paralleled in very many woodworking establishments.

### Mr. Parks's Closure

Replying to Mr. Ross, our experience has been that it costs just as much, if not more, to dry refuse outside of the furnace by some auxiliary use as it does in the furnace. In other words, it takes no more B.t.u. in one place than another.

In one industry in which we have done considerable work,

the tanning industry, the so-called "spent" bark from the leach where they make their tanning liquids, is delivered to the boiler house with a water content of about 65 per cent. We made some experiments at one plant by running this refuse, this spent tan bark, through what might be called a wringer, and attempted to press out part of the moisture. The experiment was successful in that it indicated that about 10 per cent of the moisture could be removed, but that is about all that can be extracted by auxiliary mechanical methods. While the experiment was fairly successful, the removal of that 10 per cent did not seem to justify expending the power required to run the wringer. So it was finally given up and the refuse spent bark was simply delivered to the furnace, carrying 65 per cent moisture. That meant, of course, that a lot of heat had to be spent in drying it, but at the same time there was a net value resulting that was quite considerable.

In regard to Mr. Baxter's comments, it is of course rather a difficult problem to control the air when spouting refuse shavings direct from the separator into the furnace. As Mr. Baxter says, there is a large amount of air required in order to mechanically transport the shavings. I know of no good way of controlling that air in accordance with the fuel where spouting direct from the separator.

Mr. Winholt, I believe, has accomplished considerable in that line by the use of that balanced damper which acts as a sort of obstruction in the path of the air, and forces more of it to be discharged through the regular vent on the separator.

Another experiment we conducted was at the plant of the Grand Rapids Store Equipment Company, where we used auxiliary feeding equipment, taking the refuse out of the bottom of the shaving bin and employing an auxiliary separator in order to reduce the amount of air. I do not know of any good way of controlling the air exactly in accordance with the fuel except by using something like a screw feeder direct from the furnace bin into the furnace, where the shavings are delivered into the furnace practically without any air, and the air is controlled either from above the grate or through an auxiliary air inlet, or by some similar means.

Referring to Mr. Bilhuber's discussion, I have never had much experience in pulverizing anthracite coal. We get very little of it in our district for plants. Pulverized bituminous coal, however, has given quite satisfactory results. Where the furnace volume is sufficiently large we have had quite satisfactory results and fairly high efficiency, both in using the refuse alone and the powdered coal alone in the same general type of furnace.

Replying to Mr. Gordon, in the majority of plants it has been impossible, unfortunately, for us to get the stack data because there are very few plants—in our neighborhood, at least—that are equipped with apparatus and instruments that enable one to make these tests. Naturally, while we should like to obtain the benefit from making these tests, we cannot go to the expense ourselves in all cases, and in many cases the owners are unwilling to make the outlay themselves.

In a wheel-manufacturing plant in Lansing, Mich., we got rather poor efficiencies and poor results so far as $CO_2$ was concerned. We were cramped for room and could not get the furnace volume we wanted.

In the larger furnace described in the paper with the closed type of boiler, using pulverized coal, we got an efficiency of about 72 per cent burning wood refuse, with a stack temperature of about 500 deg. fahr.; burning coal, the efficiency was about 76 per cent.

With reference to the question asked by Mr. Norris, in general, I should say with only 10 per cent of the fuel used being wood refuse, the determining factor in the furnace design would be largely the use of coal. At the same time it would seem that that furnace should be designed so that wood refuse could be used to advantage, for it would have a decided fuel value, and it would be better to burn it under the boiler than outdoors.

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